Minutes of proceedings of the Institution of Civil Engineers

Institution of Civil Engineers (Great Britain)

Thoˢ Kell & Son

WILLIAM HENRY PREECE, C.B., F.R.S.

ELECTED PRESIDENT 26 APRIL, 1898.

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VOL.

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[*The right of*

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXXXV.

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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CORRIGENDA.

Vol. cxxxii. p. 358, line 30, *for* "a flexible hose" *read* "an extension-pipe."
" cxxxiv. p. 459, " 21, *for* "Wiborg" *read* "Wiborgh."
" p. 463, " 21, *for* "1895" *read* "1898."
" p. 465, " 15, *for* "dressing, fluor" *read* "dressing-floor."

THE
INSTITUTION
OF
CIVIL ENGINEERS.

SESSION 1898-99.—PART I.

SECT. I.—MINUTES OF PROCEEDINGS.

1 November, 1898.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

THE PRESIDENT, on taking the Chair for the first time after his election, observed that he had been President of the Institution for 6 months, but the present was the first occasion on which he had had the opportunity of meeting the members in that capacity. There seemed to be something still wanting in the By-laws of the Institution, and it was his intention to take an early opportunity of bringing the matter before the Council, with a view to a re-arrangement, by which the induction of the President to the Chair should be coincident with the commencement of the Session and the date of his Address.

During the past six months Death had been remorseless with his scythe. Several familiar faces were missing from the Council table, and many other members had disappeared for ever. The Institution had lost two Past-Presidents. Sir Robert Rawlinson had died at the ripe old age of 88; and Harrison Hayter's judicial head would be missed from the Council table; Sir James Douglass, a former Vice-President, had succumbed; and last, but not least, one had been taken away by the most tragic accident that had ever happened in the Alps—one who had scarcely completed his fiftieth year, and whom the Institution could ill afford to lose. John Hopkinson was a valued neighbour of his, and the intimate friend of many of the members; he was a devoted engineer, an accomplished scientist, an athlete in mathematics, and was regarded by every one as an authority in at least two branches of the profession. He need hardly say that the Council had taken the first and most rapid means of expressing the feelings of the members of the Institution at such a dreadful loss, and their sympathy with those nearest and dearest to him. Only

within the last three days another sad loss had occurred—one who was not a member of the Council, but with whom, from 1852 to 1856, the President had worked, more as a brother than a subordinate. He had been Latimer Clark's assistant during those years, and had never worked with a more earnest, honest and faithful compeer. It was with a feeling of great regret that he had to announce his demise.

The President then delivered the following Address:—

The election to the position of President is the highest possible reward which the Institution can give to those who have endeavoured to serve it well and truly. I have often feared that my position as a specialist might have proved a bar to the attainment of my greatest ambition. It has come at last. I am very grateful, and I promise that I will continue to do my very best to merit your confidence and approbation. I am also proud, not alone for the sake of that branch of the profession to which I specially belong, but also because I am a member of the great Civil Service of this country. Twenty-eight of my forty-six years of professional work have been spent in the service of the Crown. I can speak with some authority and experience when I assert that this Service deserves a recognition for zeal, industry, and the conscientious determination to do its duty far greater than that usually accorded to it by Parliament, the public, and the press. The jealousy and contempt so freely displayed for Government work are not justified by results. It is the fashion to decry the public service. It is probably a survival of that old feeling of oppression and dissatisfaction which the ruled always felt towards their rulers. The position is now reversed—the public is the master and the official is the servant. The public servant is not to be coerced by oaths or driven by whips or deterred by scorns. His labours should be sweetened by praise, and his successes acknowledged by a grateful recognition. Two of your Vice-Presidents belong, and some of your Council have belonged, to this Service. You at any rate are free from criticism, for you have testified to my zeal by giving me the greatest reward you can confer. My successors will be able to drive home the nail I desire to insert in the coffin of the traditional general and false belief in the inefficiency of a great and growing public service.

I entered the Institution as an Associate in 1859, and am now in my fortieth year of membership. It is interesting to see the growth of the Institution during that period:—

ROLL OF THE INSTITUTION OF CIVIL ENGINEERS.

—	November, 1859.	October, 1898.
Honorary Members	25	20
Members	332	1,946
Associate Members	..	3,940
Associates	523	320
Graduates	14	..
Students	..	862
Total	894	7,088

The distribution of our 7,088 members over the globe is shown in this Table:—

DISTRIBUTION TABLE.

—	United Kingdom.		India with Ceylon and Burma.	South and East Africa with Transvaal.	Australasia.	Canada with British Columbia, Nova Scotia, and Newfoundland.	British Possessions—Miscellaneous.	United States.	Other Countries.
	Resident.	Non-Resident.							
Hon. Members.	12	4	..	..	..	..	..	1	3
Members	555	790	162	50	140	45	25	65	114
Assoc. Members	970	1,690	350	180	270	30	90	45	315
Associates	175	100	12	4	8	1	2	5	13
Students	275	417	60	20	40	5	20	5	20
Totals	1,987	3,001	584	254	458	81	137	121	465

Roughly we can say that 71 per cent. are Home Members, 21 per cent. are Colonial Members, and 8 per cent. are Foreign Members. It is not alone in numbers that growth is shown; it is more so in the business of the engineer. The field of the profession has extended in all directions by the advances of practical science and by a process of evolution and agglutination. The introduction of the steam-engine, the development of the railroad, the invention of the paddle and the screw, and the evolution of the ocean greyhound; the conversion of iron into steel, and the demand for ores; the opening of coal- and oil-fields and the production of gas; the sanitation of our dwellings and

our towns, and the demand for pure air and pure water; the applications of electricity and the annihilation of distance; the rifling of ordnance, the improvement of explosives, and the armouring of great fighting, floating, moving machines; the enormous growth of manufactures and their distribution over the face of the earth; the pursuit of wealth, the roving propensities of our race, and the industrial competition of nations;—have all contributed to break up our profession into special branches and into individual groups, with their separate organizations and with their independent homes. Thus we have the railway engineer, the mechanical engineer, the naval architect, the mining engineer, the sanitary engineer, the gas engineer, the hydraulic engineer, the electrical engineer, the chemical engineer, the marine engineer, species of one genus—the civil engineer, whose home is in this building, whose Institution, like a good mother, tries to keep them all under the protection of her wings, and who is prepared to make any sacrifice to advance the knowledge of engineering, and to maintain the solidarity and reputation of the profession. The Engineering Conference held by the Institution in 1897 was undertaken in the furtherance of this aim, with results so successful as to call for its repetition in the approaching spring of 1899.

Examinations.

Our great European rivals relegate the examination and selection of their engineers to their Governments, but we, under the guidance of our immediate Past-President, have taken this load on our own shoulders; not before it was needed, for the competition of highly educated engineers of other countries was becoming rather too evident. Loss of business is a potent force to effect reform. The reform itself in our case has materially strengthened the credentials of our Institution.

Our task has been a difficult one, for, while we recognise most fully that the practical training of the drawing-office, of the shop and of works in progress are the true school for the engineer, we cannot help thinking that he ought to acquire that knowledge which is the basis of his profession and those exact methods of inquiry and of thought which lead to truthful deduction and to sound judgment, before he can satisfactorily begin his professional experience.

The foundation of engineering is science. Science is not only a knowledge of the facts of Nature but of the development of her laws. It is, in the language of Huxley, organised common sense. The

man who determines to practise in the business of applying those facts and laws to add to the comfort and happiness of mankind must know something of the mental tools and weapons that mathematics and logic have placed at his disposal. His mind must be trained to habits of enquiry, and he should know something of the experience and teaching of the past. Hence the Institution, as the tutelary genius of the profession, has established a system of qualifying, not competing, examinations for admission into its ranks; not only to test the education and preparation of those who wish to recruit our numbers, and the qualifications of those who desire to improve their position in our classes, but also to enhance the standing of the modern engineer as the most scientific and advanced of all the learned professions. The result of the first examinations has been highly satisfactory. Out of 24 examined for Studentship, 3 only failed to pass. Of 40 examined for Associate Membership, 7 failed. Of 48 theses submitted in lieu of examination, 5 only failed to secure a satisfactory report. The popularity of the measure among even the examinees is shown by the entrance of 71 for this last October examination.

The examination papers which have been set are by no means of an insignificant character, yet 86 per cent. of marks have been acquired on the whole examination.

Our ancient Universities commenced their careers as mind-training establishments, with faculties of Theology, Law, and Medicine. These were called, and still are known, as the learned professions, but subsequently Arts was added, from which has sprung all modern science. Engineering as the principal outcome of this faculty has been the mother of scientific progress. A mere University training alone does not lead to invention and discovery. It is contact with the practical world, a knowledge of wants and defects, which excite discoveries and improvements. The modern method of research proceeds by making experiment subservient to hypothesis. Difficulties teach effects, effects suggest causes, a knowledge of causes leads to remedies, and finally to exact science. Practice, the home of difficulty, is thus the nursery of science. The engineer is far in advance of the pure scientist. Smeaton and Watt, Telford and Stephenson, Rankine and Kelvin, Whitworth and Froude, Regnault and Hirn, have established not only the profession of the scientific engineer, but they have laid the groundwork of science itself.

Technical Education.

The engineer extracts matter from the earth and transforms it into purer and more serviceable forms. He finds energy lying dormant or running to waste; he converts it into active and useful forms. A knowledge of matter and of energy is the foundation of all his actions. This, combined with the power of thinking so as to enable the brain to direct and assist the hand, is the root of what is known as technical training. The modern engineer has immense advantages over his predecessors. He can commence his practical career with a University training, well charged with facts, wanting only that experience which practice alone will give.

There is a fashion in Great Britain for technical education just now. Enormous sums of money are being annually spent on secondary, intermediate, and more advanced education. It is well that it is so. It is well that the country has awakened from its conservatism and apathy, and that it is putting its schools in order. But is it doing so on a true issue, and are we distributing our money through the right channels? Our trade is suffering even in our own colonies from the competition of our continental neighbours, who are said to be beating us by their technically superior hand labour. It is true we are suffering, but is this the true cause? It is rather from the superior commercial skill of the principals at home and the accomplished polyglot and well-trained traveller abroad, as well as from a financial system that is more moral and more sound than that rampant in England through the gross abuses of the Limited Liability Act of 1862. Our law courts are almost daily the scenes of the exposure of the modern spoiling of the Egyptians. A new industry is designed by some simple, well-devised, and economical process. Capital is required to develop it. In Germany, financial support is readily subscribed by the generous and enlightened policy of its banks. In England we require a syndicate, a pioneer company, and finally an appeal to the public for an enlarged limited company. The financiers, the lawyers, the brokers, as well as the original inventor, have to be satisfied, and this satisfaction grows very much with the state of the money market and the excitement for investment with the public. The industry is established, but with a terribly overloaded capital—overloaded by the harpies who have sprung from the operations of the Limited Liability Act. The same industry could be established in Germany with probably half the capital. Its manufacture would be supervised there with greater skill, and it

would be developed as a business by better trained agents. We are thus fairly beaten on our own commercial preserves.

Our educational methods have begun at the wrong end. We ought to teach the masters first and then the men. Moreover we have to teach the teachers and those who have control of the purse-strings. The County Councils of England are scarcely qualified as yet to discharge the very serious duty of properly dealing with a question so few of them understand—though many of them have tackled the matter manfully, especially the London County Council, through its Technical Education Board on which a large proportion of co-opted experts have seats, who, by supporting existing institutions, have contributed towards the supply of teachers. But how are we to approach the masters? A fault once discovered is halfway to repair. It is difficult to remove the scales from the eyes of the man who has been successful in business and who knows not of his blindness; but the coming generation will be more enlightened, and the future masters better educated.

We are suffering from a lack of competent teachers. A teacher who has had no training in the practical world is worse than useless, for he imparts ideas derived from his inner consciousness or from the false teaching of his own abstract professor, which lead to mischief. In my own experience I have met with very serious inconveniences from this cause. The ideal professor of pure abstract science is a very charming personage, but he is a very arrogant and dogmatic individual, and, being a sort of little monarch in his own laboratory and lecture-room, surrounded by devoted subjects, his word is law, and he regards the world at large, especially the practical world, as outside his domain and beneath his notice. He is generally behind the age. These are not the men for technical institutes. Such teachers should possess the diploma of this Institution.

Energy.

The great generalization of modern days is the principle of the conservation of energy. Energy, like matter, can neither be created nor destroyed. Its form only can be changed. It is in its various transformations that it expends or absorbs work, and thus the engineer has to consider not only the various forms of matter, but the various forms of energy. He has to expend energy on matter in such a way as to supply the wants, improve the comforts, and add to the resources of mankind. He has not

only to utilize the waste energies of Nature, but he has to economize those that are in use so as to be able to apply them in the cheapest and most effective way. Every branch of engineering is thus dominated by the application of the great principle of work, which means the expenditure of energy, for energy is simply the capacity or property which Nature possesses for doing work. The engineer must be an educated man, educated not necessarily so much in the languages, arts, and history of the past, as in the changes and properties of ever-present matter, and the forms and behaviour of never-failing energy—changes and transformations directed by his will, controlled by his knowledge, and applied by his hands. Tredgold's great definition wants modification. It should read, "the profession of an engineer is to apply the great principle of work to the use and convenience of man," and his title should be rather that of *Energeer* than *Engineer*.

Electricity.

Day by day we are startled with some new development of electricity. We have learned the truth of the aphorism that that which is sure to occur is the unexpected. It is not of arms and of man that I propose now to sing, but of energy in its most romantic form.

A happy accident in early life placed me at the feet of our electrical Gamaliel, Michael Faraday. My boat was launched on the waters of knowledge that flowed from the rocks of Nature, opened by the strokes of the magic rod of that great master. The tide was taken at the flood, and, having rolled on for nearly fifty years, it has led me to this chair.

I learned from Faraday to regard electricity as the result of the play of the atoms and molecules of matter, that it was a mere form of motion, and that its influence through space was due to the existence and operations of a medium—since called the Ether. Maxwell crystallised Faraday's views into mathematical language, and deduced the magnificent generalization that light and electrical waves are of the same kind, moving through the Ether with the same velocity, and differing from each other only in degree. Hertz proved the existence of these waves and measured their lengths, and Marconi has now applied them to the practical purposes of telegraphy. I have carefully watched every new electrical fact wrung from Nature's storehouse without ever failing to find a simple mechanical explanation of their cause.

The term "Electricity" has even been defined by Act of Parlia-

ment (45 Vic. cap. 56, 1882) as that form of energy which we make and sell. It can be measured with the minutest engineering exactness, and its effects are explicable on the simple dynamical and mechanical principles that underlie our profession.

Lightning.

The first practical application of the science of electricity was for the protection of life and property. Franklin in 1752 showed how to secure ourselves and our buildings from the disastrous effects of a lightning stroke. Very little has been done since to improve upon his plan. A Lightning-Rod Conference, upon which I served, met in 1878, and its report, published in 1881, remains an admirable and useful standard of reference. The principle advocated by Franklin was prevention rather than protection. If a building or a ship be fitted and maintained with good continuous copper conductors, making a firm electrical contact with the earth or the sea, and be surmounted well up in the air with one or a cluster of fine points, all the conditions that determine a charge of atmospheric electricity and a flash of lightning are dissipated silently away and no terrible discharge is possible. A mischievous and baseless delusion is prevalent that protectors actually attract lightning and may be sources of danger. Every exposed building should be fitted, but a well-protected dwelling-house is the exception, not the rule. Even when protectors are fixed apathy leads to their imperfect maintenance. Their failure to act is always traceable to the neglect of some simple rule. Carelessness is the direst disease we suffer from. Telegraph and telephone wires which spread all over our towns and country are very much exposed to the influence of atmospheric electrical effects. Every instrument is now protected. Every telegraph pole has a lightning conductor. Accidents are rare, and the system itself is a public safeguard. In some countries like California and South Africa thunder-storms are very frequent and very severe, but their effects have been tamed.

The engineer has answered Job's conundrum: "Canst thou send lightnings, that they may go, and say unto thee, Here we are?" in the affirmative. I sat, on the 12th June last, in a cable hut on the Welsh coast, near Nevin, with a telephone to my ear and heard flashes of lightning in Ireland, Scotland, England and Wales on the same afternoon. The sound emitted by a telephone receiver when a discharge takes place in the neighbourhood of a telephone circuit is distinctive and characteristic. It is a

signal as clear and as comprehensible as the words, "Are you there," or, "Here you are."

Franklin's work has been beneficent. He showed successfully how to bring the lightning down from heaven and how to dissipate its causes harmlessly away in the earth.

Telegraphy.

In 1837 Cooke and Wheatstone showed how electricity could be practically used to facilitate intercommunication of ideas between town and town and between country and country. The first line was constructed in July of that year upon the incline connecting Camden Town and Euston Grove Station, the resident engineer being Sir Charles Fox, father of the senior Vice-President. Five copper wires were embedded in wood of a truncated pyramidal section and buried in the ground. The instrument used possessed five needles or indicators to form the alphabet. A portion of this original line was recently recovered *in situ*. I call it the "fossil telegraph," and used this sample to complete five circuits between the General Post Office and the offices of the various Cable Companies on the Queen's Diamond Jubilee Day, for the transmission of Her Majesty's simple message, "From my heart I thank my beloved people. May God bless them!" to all our princes, governors, captains, and rulers scattered over the whole globe. To north, south, east, and west, over every quarter and every continent, under every ocean and every sea, these words flew with the speed of thought. When Her Majesty returned to Buckingham Palace acknowledgments and replies had arrived from every colony, the first to come being from Ottawa, Canada, 16 minutes after the message was despatched.

The pioneer line of 1837, 1¼ mile long, has, during this period of sixty years, grown into a gigantic world-embracing system. Every man at his breakfast-table can read an account of every stirring event that has transpired on the previous day in every quarter of the world. Distance is annihilated and time overcome.

The extent of the present system of British telegraphs is shown by the following Table:—

	Miles of Wire.
General Post Office and its Licensees	435,000
Railway companies	105,000
India and Colonies	389,760
Submarine cables	183,400
Total	1,113,160

The mechanical construction of the telegraphs of this country was designed by our late distinguished Member Edwin Clark and his brother, Latimer Clark, also a Member. Their affairs were originally directed by our Past-Presidents, Robert Stephenson, Bidder, and Locke. We in this country have always been in advance of other countries in telegraphic progress, and this was greatly due to the inventive genius of Cromwell Varley, a Member of the Institution. These are men under whom I served and learnt, and whose engineering traditions I have done my best to maintain and to better. Progress has never been checked. The speed of signalling and the capacity of working have been increased sixfold, and wires can now be worked faster than messages can be handled by the clerical staff.

The form of submarine cable and the nature of the materials used in its construction have varied but very little since the first cable was laid in 1851. The recent invasion of our channels and seas by the *Limnoria terebrans*, a mischievous little crustacean which bores through the gutta percha insulating covering, and exposes the copper conductor to the sea-water, leading to its certain destruction, has led to the use of a serving of brass tape as a defence. It has proved most effective.

No one has done more than Lord Kelvin (Honorary Member) to improve the working of submarine cables. His recording apparatus is almost universally employed on long cables. By the duplex method of transmission the capacity of cables has been practically doubled, and this has been still further improved by applying to cables the system of automatic working, which is such a distinguishing feature of our Post-Office system. The number of electrical impulses which can be sent through any cable per minute is dependent upon its form, and is subject to simple and exact laws, but it varies with the quality and purity of the materials used. There is no difficulty in maintaining the purity of copper. Indeed copper is frequently supplied purer than the standard of purity adopted in this country—known as Matthiessen's standard. The purity of gutta percha is, however questionable. The supply of this dielectric has dwindled; it has failed to meet the demand; its cultivation has been neglected. The result is a dearth of the commodity, a great increase in price, and its adulteration by spurious gums. India-rubber, its sole competitor for cables, is being absorbed for waterproof garments and pneumatic tyres, but for underground purposes paper is being used to an enormous extent. Paper has the merit, when kept dry, not only of being an admirable insulator, but of being very durable. There is

paper in existence in our libraries over 1,000 years old. The difficulty is to keep it dry. This is one of the problems the engineer delights to consider. He has been most successful in obtaining a solution. The lead-covered paper cables, which are being laid in the streets of all our great cities, are admirable. I am laying one of seventy-six wires for the Post-Office telegraphs between London and Birmingham, and the Cable Companies are contemplating leading their long cables from Cornwall up to London, so as to be free from the weather troubles of this wet and stormy island.

It is impossible to forecast the future of telegraphy. New instruments and new processes are constantly being patented, but few of them secure adoption, for they rarely meet a pressing need or improve our existing practice. The writing telegraph originating with our late Member of Council, E. A. Cowper, which reproduced actual handwriting, much improved by Elisha Gray, and called the "Telautograph," is steadily working its way into practical form, and electrical type-writing machines of simple and economical form are gradually replacing the A B C visual indicator. The introduction of the telephone is revolutionising the mode of transacting business. There seems to be a distinct want of some instrument to record the fleeting words and figures of bargains and orders transmitted by telephone. Hence a supplement to that marvellous machine is needed. The telautograph and electrical type-writer will fill this want. Visions of dispensing with wires altogether have been fostered by the popularity of Marconi's "wireless telegraphy"; but wireless telegraphy is as old as telegraphy itself, and a practical system of my own is now in actual use by the Post Office and the War Department. Sensational experiments for booming a new financial enterprise are not processes that commend themselves to the Institution. We want practical work and engineering progress.

TELEPHONY.

I was sent, in 1877, together with Sir Henry Fischer, to investigate the telegraph system of the American Continent, and especially to inquire into the accuracy of the incredible report that a young Scotchman named Bell had succeeded in transmitting the human voice along wires to great distances by electricity. I returned from the States with the first pair of practical instruments that reached this country. They differed but little from the instrument that is used to-day to receive the sounds.

The receiver, the part of the telephone that converts the energy of electric currents into sounds that reproduce speech, sprang nearly perfect in all its beauty and startling effect, from the hands of Graham Bell. But the transmitting portion, that part which transforms the energy of the human voice into electric currents, has constantly been improved since Edison and Hughes showed us how to use the varying resistance of carbon in a loose condition, subject to change of pressure and of motion under the influence of sonorous vibrations. The third portion, the circuit, is that to the improvement of which I have devoted my special attention. Speech is now practically possible between any two post-offices in the United Kingdom. We can also speak between many important towns in England and in France. It is theoretically possible to talk with every capital in Europe, and we are now considering the submersion of special telephone cables to Belgium, Holland, and Germany. The progress of the use of the telephone in Great Britain has been checked by financial complications. It fell into the hands of the company promoter. It has remained the shuttlecock of the Stock Exchange. It is the function of the Postmaster-General to work for the public every system of intercommunication of thought which affects the interests of the whole nation. Telephony is an Imperial business, like the Post and the Telegraph. It ought to be in the hands of the State. The public and the press have frequently kicked violently against the present régime. Committees of Parliament have sat and deliberated upon the question. The report of the last committee is now under consideration.

"*Quidquid delirant reges, plectuntur Achivi.*"

Two causes exist to impede this desirable absorption, the fear of being "done" by watered and inflated capital, and the assumed bad bargain made in absorbing the telegraphs in 1869. The former is a mere bugbear. The public does not want to purchase stock. It wants to acquire a plant and business, which can be easily and fairly valued. The latter is a gross fallacy. The business of the Telegraph Companies—practically an unlimited monopoly—was purchased on absolutely fair terms, viz., 20 years' purchase of the net profits. The sum paid was £4,989,048. The number of messages then sent in one year was about 5,000,000, and the gross income about £500,000. The income has now grown to £3,071,723, the number of messages has reached 83,029,999, and the capital account which was closed in 1891, viz., £10,131,129, including the cost of the Post Office extensions,

remained the same. If a syndicate desired now to re-purchase the business and acquire the plant, they would have to find a capital of over £30,000,000. In what respect, then, was the transfer of the telegraphs to the State a failure? Our magnificent system has been built virtually out of revenue, our tariff is very cheap, scarcely a village of any consequence is without its telegraph, our press is virtually subsidized by having its news supplied at much less than cost price; we can rely upon safe and accurate delivery, and upon speedy despatch of messages. We lead the world. There has been no failure, and there was no bad bargain.

The present condition of the Telephone business in this country is shown by the following return:—

TELEPHONES IN USE.

National Telephone Company	(30th June, 1898) . .	133,498
Railway Companies	(„ „) . .	15,911
General Post Office	(„ „) . .	9,588
Total	. . . .	158,997

RAILWAYS.

The regulation of the traffic on a railway, and the general business of the line, could not possibly be conducted without the telegraph. The safety of the passenger and the freedom from collision are due to the introduction of the block system, which is worked entirely by electric signals, and which has been made compulsory by Parliament on all British railways. It was my good fortune to have taken a very active part in the introduction of the block system, especially in the assimilation of the working of the indoor (electric) and the outdoor (mechanical) systems of signalling and in their interlocking. More recently, the control of the traffic and the secure working of single lines by the Tablet and electrical train-staff have been carried to a very high state of perfection. Distant signals can now be fixed anywhere out of sight of the signalman who works them, for the position of the semaphore by day, or the character of the light by night, are repeated back by electricity upon miniature signals, fixed in the signal box. The state of the signals can even be indicated on the engine to the driver in foggy weather or by night, and the state of distant points shown to the signalman in all seasons.

The regulations of the Board of Trade, regarded often as unnecessary interference by railway men, together with the careful engineering inspection before the opening of a line, and a judicial inquiry in case of accident, have tended more than anything else to add to the security of railway travelling.

In 1897, 24 persons, including 6 railway servants when travelling, were killed from accidents beyond their own control. This was above the average. It has been said that a first-class compartment on one of our great railways is the safest place in the world. It is safer than bed, for, in 1896, 1,809 persons were suffocated in bed. It is safer than a dining-room, for, in the same year, 148 people were choked by food. 925 were killed by falling down stairs. Bicycles are far more destructive to life. Accidents in the streets of London are so frequent, and therefore so uneventful, that they are not even recorded in the press. Accidents on railways are so rare and eventful that columns of large type are devoted to a description of their minutest details.

The safety of railway travelling as effected by modern improvements in working is shown by the following facts:—

1874 . . .	1 person in	5,556,284	journeys	was killed.
1884 . . .	„	22,419,092	„	„
1894 . . .	„	56,963,307	„	„
1896 . . .	„	196,067,887	„	„

The train accidents in—

1878	were	108
1888	„	61
1897	„	48

More than 50 per cent. of the causes of these accidents were due to the negligence, want of care, or mistake, of those conducting the traffic, which emphasizes my previous statement that carelessness is the direst disease we suffer from.

The employment of electricity in the working of railways has not only been highly beneficent in the security of human life, but it has vastly increased the capacity of a road to carry trains. The underground traffic of the metropolis is conducted with marvellous regularity and security, though the trains are burrowing about in darkness and following each other with such short intervals of time that the limit of the line for the number of trains has been reached. Electric traction is going to extend this limit by increasing the acceleration at starting and improving the speed of running. It will also reduce the cost of working per train-mile, so that the advent of electricity as a moving agency is

certain to prove highly economical. What it will do as a remover of bad smells and foul air and for personal comfort cannot be estimated. Time alone will enable us to assess the intrinsic value of public satisfaction acquired by the change.

The extent to which electrical appliances are used on the railways of this country is shown by the following Tables:—

Table I gives the number and description of the various classes of electrical apparatus in use on railways in the United Kingdom in the year 1898:—

Description.	Total.
Single needle instruments	20,800
Morse sounders	435
„ recorders	12
Telephones	15,911
Duplex apparatus (complete)	33
Bell instruments (for message work, complete, with keys, relay and galvanometers, &c.)	615
Phonopores (complete)	207
Block instruments	35,689
Train staff instruments	1,621
Tyer's tablet instruments	1,499
Interlocking „	5,640
Repeater „	25,569
Treadles	2,668
Fouling bars	856
„ bar indicators	361
Replacers	180
Slot selectors	408
Single-stroke and relay bells	25,095
Galvanometers	736
Large trembler bells (platform, &c.)	2,674
Small „ „	8,080
Night and day switches	6,585
Fire-alarm commutators	149
Train describers	479
Light indicators	2,846
Signal repeater disks	924
Test-boxes	114
Water-tank apparatus	13
Telephone switch-boards	17
Bell-indicators	87
Point detectors and indicators (various)	19
Signal lever-lock	345
Extra contact-makers and switches	210
Magneto electric bells	4
Relays	361
Special appliances (various)	2,771
Total	164,013

Table II gives the length of double and single line in the United

Kingdom open for passenger traffic on the 31st December, 1895, the latest period for which returns have been published, and the length of such lines worked upon the various systems:—

—	Line Open for Passenger Traffic.		Worked on Absolute-Block System.				Worked on other Telegraph Systems.		Single Lines worked under—		
				Single Line.							
	Double.	Single.	Double Line.	Combined with Train-Staff System.	Without Train-Staff System.	By Electrically-controlled Train-Staff or Tablet.	Double Line.	Single Line.	Single-Engine System.	Train-Porte System.	Train-Staff System.
	Miles	Miles	Miles	Miles	Miles	Miles	Miles	Miles	Miles	Miles	Miles
England and Wales . .	9,325	4,472	9,310	2,200	20	1,847	15	29	228	1	147
Scotland . .	1,314	1,768	1,312	210	32	1,066	1	..	427	1	31
Ireland . .	613	2,534	613	494	1	1,824	..	..	118	..	98
United Kingdom . .	11,252	8,774	11,235	2,904	53	4,737	16	29	773	2	276

Domestic Appliances.

The introduction of electricity into our houses has added materially to the comfort and luxury of home. If we were living in the days of ancient Greece, the presiding domestic deity would have been *Electra*. The old bellhanger has been rung out by the new goddess. Electra has entered our hall-door, and attracts the attention of our domestics, not by a gamut of ill-toned and irregularly excited bells, but by neat indicators and one uniform sound. The timid visitor fears no more that he has expressed rage or impatience by his inexperience of the mechanical pull required at the front door. The domestic telephone is coming in as an adjunct to the bell. Its use saves two journeys. The bell attracts attention, the telephone transmits the order. Hot water is obtained in half the time and with half the labour. Fire and burglar alarms are fixed to our doors and windows; clocks are propelled, regulated and controlled. Even lifts are hoisted for the infirm and aged. Ventilation, and in warmer countries coolness, are assisted by fans. Heating appliances are becoming very general where powerful currents are available. Radiators assist

the coal fire by maintaining the temperature of a room uniform throughout its length and breadth. Ovens are heated, water is boiled, flat-irons become and are maintained at a useful temperature, breakfast dishes and tea-cakes are kept hot, even curling-tongs have imparted to them the requisite temperature to perform their peculiar function.

ELECTRIC LIGHT.

But it is in supplying us with light, without defiling the air we breathe in our dwellings with noxious vapour, that electricity has proved to be a true benefactor to the human race. The Legislature has facilitated the acquisition by municipalities of those local industries that affect the welfare of the whole community, such as road-making, sewerage, the supply of water, tramways, and, above all, electric light. No one doubts that new industries of a speculative character are best pioneered by private enterprise. The company promoter has, however, so abused the power placed in his hands by the Limited Liability Act that, not only has the development of electric lighting been retarded in this country, but the prospect of private enterprise in furthering other industries has been checked. Fortunately the success, the comfort, the intrinsic value, the economy and the sanitary properties of electric light have commended it to our municipal magnates, and its introduction has become the fashion. The following Table shows the position of the industry in this country and in the United States at the present time:—

ELECTRIC LIGHT UNDERTAKINGS.

—	United Kingdom.		United States.	
	Municipalities.	Companies.	Municipalities.	Companies.
Number of central stations	72	63	338	2,251
Capital stock . . . £	4,599,154	3,258,343	3,419,019	48,207,527
Number of arcs . . .	5,753	1,259	26,087	265,064
Number of glows . . .	1,393,514	1,936,893	693,984	14,278,358
Kilowatt capacity . .	44,219	24,344	41,193	578,051

In spite of our financial troubles, of the inertia of municipal bodies, of the active competition of vested interests, our progress compares not unfavourably with other European countries, but

the progress of the industry in the United States has been phenomenal. The return for the United Kingdom is, however, by no means complete. It omits all private installations. We in the Post Office alone have 50,000 lamps which are not enumerated; and if we consider all our great railway companies, banks, warehouses, manufactories, and shops which have their own installations, the statistics will be very considerably extended. Lamps are being improved and cheapened, wiring is being reduced in cost, and the economic distribution of energy is being furthered. But the most promising field for economy is the combination of all classes of electrical industry in one centre, especially that of light and tramway working where fuel is cheap, water abundant for condensing, and nuisances of no account. The cost of the production of electrical energy depends principally upon the continuity of its output. If it can be generated continuously during the 24 hours of the day its cost is only a fraction of a penny per unit. If it is used solely for light, a unit may cost threepence. Hence local authorities, who are undertakers of electric energy, neglect their duty to those who have elected them as the custodians of their interests if they fail to secure the tramways in their district, either as their own property or as customers for their current. For the tramways, by taking energy during the day, reduce the cost of working during the night by removing the incubus of running continuously imposed on undertakers by Act of Parliament. This may enable the ratepayers to be supplied at a price for electric light certainly one penny per unit less than if there were no tramways. The cheaper the supply of energy per unit the more certain and speedy the advent of the electric light as the poor man's lamp, and the more beneficial its introduction into the confined, ill-ventilated and overcrowded homes of the working classes. By improving locomotion to the suburbs and enabling them to live in pure air, and by clearing the air they breathe of the impurities due to the combustion of tallow, oil and gas, the more readily should the public fall down and worship the golden image which Parliament and science have set up.

It is on board ship that electric light has been pre-eminently successful, and where it filled such a crying want that its introduction met with no check. It was almost immediately and universally adopted. Search lights, prompted by the great development of the torpedo, were introduced into our Navy as early as 1875 by Mr. Henry Wilde. The first ship to be fitted with internal electric lighting was the "Inflexible" in 1882. In 1884 the Admiralty ordered it to be applied to all H.M. warships.

The first application of electrical power was in the case of H.M.S. "Barfleur," where motors were used for working guns and for the supply of ammunition. It has subsequently been partially extended to the working of gun-turrets, ventilating fans, capstans, and boat-hoisting gear; but hydraulics, the child of our venerable Past-President, Lord Armstrong, is the form still more generally preferred and used for power in our Navy, though other nations make a much more extended use of electricity. The technical reports received by the United States Navy Department indicate that the electrical appliances on their warships worked very successfully during the recent war. Electrical conductors are readily stowed away in safe quarters, and easily repaired when severed by shot. The electrical energy used in a first-class battleship is expended thus:—

Internal lighting	60 E.HP.
Search-lights	65 ,,
Ventilation	30 ,,
Capstans, hoists, &c.	60 ,,
Reserve	45 ,,
Total	260 ,,

Number of glow-lamps	1,000
,, ,, search-lamps	6
,, ,, ventilating fans	16
,, ,, motors	2 to 8

The following Table illustrates the progress of electric work done by that branch of the service which is so eminently presided over by our Vice-President, Sir W. H. White:—

Year.	Ships fitted with Electricity.		Total Number fitted.		Electric Machinery.	
	Search-Lights.	Internal Lighting.	Search-Lights.	Internal Lighting.	Number of Sets fitted.	Total E.HP.
				Number of Lamps.		
1876	Nil	Nil	Nil	Nil	Nil	Nil
1876 to 1880	19	Nil	38	Nil	19	33
1880 ,, 1884	30	1	50	..	30	120
1884 ,, 1888	150	30	220	8,000	180	3,700
1888 ,, 1894	265	126	750	50,000	450	15,000
1894 ,, 1898	500	240	1,100	95,000	800	25,000

Lighthouses.

The introduction of electricity into our lighthouses has not been such an unqualified success as into our ships. No new electric light has been installed on the coast of Great Britain since St. Catherine's (Isle of Wight) was fitted up in 1888. Other electric lamps are to be found at the South Foreland, at the Lizard, and at Soutar Point, only four lighthouses in all upon our coasts.

This is due chiefly to the great prime cost of its installation and to the annual expense of its maintenance. But the sailor himself is not enamoured of it. It does not assist him in judging distances. It is too brilliant in clear weather, while in bad weather it penetrates a fog no further than an ordinary oil lamp. Moreover, great modern improvements have rapidly followed each other in other apparatus, lenses and lamps. A third-order light of to-day can be made superior to a first-order light of ten years ago. Oils have improved and gas has been introduced. Lord Kelvin proposed that lighthouses should signal their individuality to passing ships by flashing their number in the Morse alphabet. But the Morse alphabet, in 1875, was as unknown as Egyptian hieroglyphics to our nautical authorities. The same end was obtained with less mental exertion by occulting and group-flashing systems.

A new and very promising plan has recently been introduced in France, called the "Feux-éclairs" or "lightning flash" system. It has been installed in many places, but especially at the two Capes dominating the Bay of Biscay. Nothing more brilliant or more effective is to be seen anywhere than the lights that rapidly sweep across the horizon, like well-directed flashes of summer lightning, with a motion that conveys the idea of a wave of some illuminated spirit-arm warning the navigator away from the rocky dangers of Ushant.

Our Trinity House has not yet introduced this plan. Any change of our well-considered and deeply-important coast-lighting system is not to be hastily effected. We are very proud of our well-guarded shores. Every headland and landfall, every isolated rock, all dangerous shoals and banks and narrow channels in lines of trade are so illuminated that navigation by night is as safe and easy as by day. Lighthouses and lightships stud our channels. Most of them are placed in direct communication with our Post Office telegraph system, so that the speediest help can be secured in moments of difficulty and danger.

We, however, want improvement during fogs and storms. Here electricity steps in. I wrote, in 1893, of wireless telegraphy:—

"These waves are transmitted by the ether; they are independent of day or night, of fog or snow or rain, and, therefore, if by any means a lighthouse can flash its indicating signals by electro-magnetic disturbances through space, ships could find out their position in spite of darkness and of weather. Fog would lose one of its terrors, and electricity become a great life-saving agency." We are nearing that goal.

Traction.

Electrically worked railways originated in Europe. The first experimental line was constructed by Dr. Werner Siemens in Berlin in 1879. When I visited America in 1884 there was only one experimental line at work in Cleveland, Ohio. Now there are more miles of line so worked in Cleveland alone than in the whole of the United Kingdom. The reason for this is not difficult to comprehend. The climatic influences of the States, the habits of the people, the cost of horseflesh, the necessity for more rapid transit, soon proved the vast superiority of electric over every other form of traction. Horses and cables will soon disappear. In England the Tramways Act of 1870 has been restrictive. It deferred the real solution of the question for 21 years. Its avowed tendency has been to throw the industry into the hands of the municipalities. Private enterprise has therefore not been encouraged, and municipalities have not taken it up. Local authorities have now been educated. The successful progress in the States and on the Continent has proved contagious, and everywhere our great cities are rising to the occasion. Indeed, to neglect to supply tramways where they would be useful, healthful, and valuable, is to a certain extent an abuse of the trust confided to the municipality by the Legislature. Rapid and convenient suburban transit is a social factor of great importance to the working classes, who can be readily transported from close quarters to pure air and healthy dwellings. Hamburg is one of the best trammed cities on the Continent. The trams were constructed by private enterprise under lease from the municipality. The latter supplies the electric energy. The tramway company is bound to take the current at a fair and reasonable price, but they have also to pay a tax on the gross receipts, which is set aside by the local authority as a sinking fund, so that on the expiry of the agreement the town will have the capital to purchase the tramways. Corporations in this

country who have secured a provisional order for the installation of electric light have secured also legal powers to supply electric energy for all purposes. It is therefore their right, and it may become a very valuable property. The duplication and multiplication of central electrical stations is likely to become a serious evil. It is absurd to see two buildings erected where one only is needed, and two causes of nuisance perpetuated where none need exist. I have already pointed out the economy of combining electric lighting and tramway working. The relative merits of overhead and underground conductors, and the use of storage batteries, are practically the only important engineering questions under discussion. The underground conduit system has been materially helped by the practical object lesson to be seen in New York, where the tramways are being very successfully worked on this plan. The trolley system is much more economical. Its erection does not interfere with the traffic of the streets. The principal objection to it is its anti-æsthetic appearance, but it is wonderful how ideas of utility and the influence of custom make us submit to disfigurement. What is more inartistic than a lamp-post, or more hideous than the barn-like appearance of many a railway terminus?

The corrosion of water- and gas-pipes, the disturbances of telegraphs and magnetic observatories, are serious questions arising from the introduction of powerful currents into the earth, but fortunately the remedies are simple, easily attainable, and very effective.

I have alluded to the proposed working of our underground railways. The success of the Mersey Dock line and of the South London and Waterloo lines, has placed the question beyond controversy. The problem to be solved is how is the conversion from steam to electricity to be effected without interfering in any way with the existing traffic or with the existing permanent way? This is not to be solved on paper. It must be determined by actual trial, and this is about to be done on the short line connecting Earls Court and High Street, Kensington. Electric traction as an economical measure in all cases of dense traffic is so certain that every great railway company must consider, sooner or later, the working of its suburban traffic by electricity. This experiment on the Metropolitan Underground Railways, therefore, should interest them all. It is a question deeply affecting the interests and comfort of the public and the condition of the congested traffic of our streets.

The storage battery fulfils a very important function in the

economical working of an electric railway. It equalises the pressure on the circuits. It meets the fluctuations of the load. It takes in current when the load is light; it lets out current when the load is heavy. It thus secures the continuous working of the engines at their full constant and most economical conditions, and it enables the engines to be shut down altogether when the load is very light as it is at night, in the early morning, and on Sundays.

In Buffalo the battery is charged by energy from Niagara, 21 miles away, and the local engines are shut down for 12 hours every day, and for 10 hours on Sunday.

Electric traction is invading even our streets. The number of unstable and weak-kneed cab-horses seems destined to be reduced by their electric competitor; while the pride of London—the fleet hansom—will be freed from an obstructive and not always sweet-smelling *avant courier*. When the real storage battery is produced the auto-mobile problem will be solved. At present steam and oil are active competitors.

Electro-Chemistry.

The transference of electricity through liquids is accompanied by the disintegration of the molecules of the liquids into their constituent elements. The act of conduction is of the nature of work done. Energy is expended upon the electrolyte to break it up, and the quantity thus chemically decomposed is an exact measure of the work done. Every electrolyte requires a certain voltage to overcome the affinity between its atoms, and then the mass decomposed per minute or per hour depends solely upon the current passing. The process is a cheap one and has become general. Three electrical HP. continuously applied deposit 10 lbs. of pure copper every hour from copper sulphates at the cost of one penny. All the copper used for telegraphy is thus obtained. Zinc in a very pure form is extracted electrolytically from chloride of zinc, produced from zinc blende, in large quantities. Caustic soda and chlorine are produced by similar means from common salt. The electroplating of gold, silver and nickel is a lucrative and extensive business, especially in Birmingham and Sheffield. Gold and silver are refined by this electrolysis in Russia, and nickel in the United States. Sea-water is decomposed in this way for disinfecting purposes by the Hermite process.

The passage of electricity through certain gases is accompanied by their dissociation and by the generation of intense heat. Hence the arc furnace. Aluminium is thus obtained from cryolite

and bauxite at Foyers by utilizing the energy of the Falls. Phosphorus is also separated from apatite, and other mineral phosphates. Calcium carbide, obtained in the same way, is becoming an important industry.

It is remarkable that our coalfields have not been utilized in this direction. Electrical energy can be generated on a coalfield, where coal of good calorific value is raised at a cost of 3*s.* per ton, cheaper than by a waterfall, even at Niagara.

Electro-metallurgy is now a very large business, but it is destined to increase still more, for the generation of electrical energy is becoming better understood and more cheaply effected.

The Transmission of Power.

The energy wasted in waterfalls is enough to maintain in operation the industries of the whole world. Great cities as a rule are not located near great falls; nor has a beneficent Providence provided great cities with waterfalls as, according to the American humorist, He has with broad rivers. There is but one Niagara, and we are seeing how industries are rather going to the falls than the energy of the falls is being transmitted to the industrial centres. The arbitrament of money is limiting the distance to which energy can be profitably transmitted. The Cataracts of the Nile can be utilized in irrigating the waste lands of the upper regions of the river, but their energy cannot compete, at Alexandria, with that of coal transported in mass from England.

At Tivoli, 15 miles across the Campagna, the energy of the falls is economically utilized to light Rome and to drive the tramways of that city. The electric railways at Portrush and Bessbrook, in Ireland, are worked by water-power, and Worcester, Keswick and Lynton use it in this country, but on a very small scale. It is not used more, for the simple reason that there are no more falls to use. Water-power is used very extensively in Switzerland, because it is so abundant there, and in our Colonies, especially in South Africa; but it is in the United States, especially in Utah and California, where the greatest works have been installed, especially for the transmission of energy to mines.

In mines electricity is invaluable. It is used for moving trams and for working hoists. It lights up and ventilates the galleries, and by pumping keeps them free of water. It operates the drills, picks, stamps, crushers, compressors, and all kinds of machinery. The modern type of induction motor, having neither brushes nor sliding contacts, is free from sparks and safe from

dust. Electrical energy is clean, safe, convenient, cheap, and it produces neither refuse nor side products. It is transmitted to considerable distances. In mountainous countries the economical distance is limited by the voltage which insulation can resist; 40,000 volts are being practically used between Provo Canyon and Mercur, in Utah, in transmitting 2,000 HP. 32 miles.

The following Table records some interesting installations:—

Place.	Electric Power Generated.	Pressure on Line.	Distance Transmitted.	Remarks.
	Kilowatts	Volts.	Miles.	
Eschdorf - Grünberg, Schleswig	225	10,000 (three phase)	15	One 80-HP. Siemens and Halske dynamo, driven from water-wheel; one 220-HP. S. and H. dynamo, driven from turbines (above driven through counter-shafting); one 220-HP. S. and H. dynamo, direct-coupled to engine.
Ogden, Salt Lake City, Utah . .	3,750	15,000 (three phase)	36	Plant consists of five 1,000-HP. twenty-four-pole three-phase generators, driven by Knight water-wheels running at 300 revolutions per minute.
Big Cottonwood, Utah	1,800	10,000 (three phase)	14	Plant consists of four 450-kilowatt three-phase general electric generators, each one directly coupled to a Pelton wheel.
Folsom - Sacramento, California	3,000	11,000 (three phase)	22½	Plant consists of four 1,000-HP. three-phase generators built by the General Electric Company, coupled direct to the turbine shafts.
San Antonio Creek to Pomona . .	480	10,000 (single phase)	13⅜	Plant consists of four 120-kilowatt twelve-pole Westinghouse alternators, driven by a Pelton water-power plant.
To San Bernardino, California . .			28⅜	
Rand Central Electric Works, Brakpan to Johannesberg, Transvaal . .	3,200	10,000 (three phase)	18	Plant consists of four S. and H. rotary-phase machines, coupled direct to 1,000 HP. to 1,200 HP. engines.

It is effecting a great economy in coal consumption in our workshops and factories. The efficiency of steam-driven shafting is known to be very poor. Scattered steam-engines and long steam-piping run away with money by their continuous waste of energy. The motor is used only when and where it is wanted, its efficiency is very high and it costs nothing when it is idle. It can be used either for the small power required by machines and

tools at present worked by hand, or for a goods locomotive of 2,000 HP., such as is now being used at Baltimore.

This utilization of energy at a distance is reinstating many home industries, to the great advantage of the working classes, whose time is wasted in long excursions to the factory, and whose health, morals and well-being are not improved by herding in great numbers and by incessant association with the grievance-monger and the professional agitator.

CONCLUSION.

I have touched lightly—I fear too lightly—upon some of the applications of electricity. I have confined myself, in a very general sense, to those with which I have been personally associated. I have shown how electricity began its beneficent career by protecting our lives and property from the disastrous effects of Nature's dread artillery, how it facilitates intercommunication between mind and mind by economizing time and annihilating space. It

> "Speeds the soft intercourse from soul to soul,
> And wafts a sigh from Indus to the Pole."

By its metallic nerves it brings into one fold not only the scattered families of one nation, but all countries and all languages, to the manifest promotion of peace and general goodwill. Not only does it show us how to utilize the waste energies of Nature, but it enables us to direct them to the place where they are most wanted and to use them with the greatest economy. It opens to our view Nature's secret storehouses, presenting us with new elements, new facts and new treasures. It economizes labour and purifies material. It lightens our darkness in more senses than one, and by enabling us to see the unseen, it tends to aid the gentle healing art and to alleviate both suffering and pain. It aids us in the pursuit of truth, and it has exploded the doctrine that the pursuit of truth means the destruction of faith.

I have occupied your time sufficiently I hope to impress upon you the universality of electricity. Its flood-gates were opened when our good Queen ascended the throne, and during her glorious reign it has overflown all the fields cultivated by the engineer. Though its followers are now regarded as specialists, the period is not distant when it must cease to be a speciality. Its facts and tenets, its science and practice, must form the framework of the

profession of the engineer. Every engineer must ultimately become an electrician; and electricity will be the most general, the most useful, and the most interesting form in which he applies the fundamental principles of energy to the wants, the comforts and the happiness of mankind.

On the motion of Sir Frederick Bramwell, Bart. (Past-President), seconded by Mr. Edward Woods (Past-President), it was

Resolved—That the best thanks of the Institution be accorded to the President for his Address, and that he be asked to permit it to be printed in the Minutes of Proceedings.

The President then presented the Telford, Watt, George Stephenson and James Forrest Medals, and announced the other awards made by the Council in respect of Session 1896–97.

A reception was subsequently held in the Library.

8 November, 1898.

WILLIAM HENRY PREECE, C.B., F.R.S., President,
in the Chair.

(*Paper No. 3137.*)

"The Extraction of Nickel from its Ores by the Mond Process."

By WILLIAM CHANDLER ROBERTS-AUSTEN, C.B., D.C.L., F.R.S., Assoc. Inst. C.E.

THE rules of the Institution enact that those elected into it shall submit a Paper within a year of election. In complying with this direction, the Author was satisfied that no better subject could be selected for consideration than the interesting process which marks an entirely new departure, in metallurgical practice, from the principles which have hitherto guided it. This process depends on the remarkable property possessed by nickel of forming a volatile compound with carbonic oxide, or, as it is called in modern chemical nomenclature, carbon-monoxide. When this gaseous compound is heated to 180° C. nickel is released in the metallic form.

The Author was much impressed during a recent visit to Canada with the Imperial importance of the great nickeliferous district of Sudbury, Ontario. In view of the magnitude of this deposit, the annual production of metallic nickel in Canada seems inadequate, as it has hitherto not exceeded 2,750 tons. The description therefore of any new process which affords a hope of hastening the development of this remarkable district should prove to be interesting. The deposit itself presents many points of interest. According to Professor Coleman of Toronto, the nickel ores of Ontario resemble the gold ores of Rossland in British Columbia, as they consist of a mixture of pyrrhotite (magnetic pyrites) and copper pyrites. These sulphides form enormous masses near the margin of large areas of diorite, or weathered gabbro of Huronian age, the amount of nickel contained in the ore averaging between 2½ per cent. and 10 per cent., the lower proportion being the

more common. It is worthy of note that pyrrhotine from other parts of the country, found in association with Laurentian rocks, is almost barren of nickel. The importance of the nickel deposits of Ontario may be judged from the fact that, until the mines in the Sudbury region were worked, the world's supply of the metal was drawn chiefly from the mines of New Caledonia, an island in the Southern Pacific, supplemented by the Gap mine in Pennsylvania, and a few isolated mines in Norway and Hungary. The extent of the Sudbury deposits is greater than any of these, and New Caledonia, which belongs to France, is virtually the only rival of Ontario in the production of nickel.

The ore at Sudbury is smelted into a regulus, or matte, which contains between 12 per cent. and 20 per cent. of nickel, and about the same amount of copper, although usually there is rather more copper than nickel. This matte may be enriched by suitable treatment, and is "Bessemerized" into a regulus which contains about 40 per cent. of nickel, and is specially free from iron, as the following analyses show:—

ANALYSES OF BESSEMER MATTE UNROASTED.

——	I.	II.
	Per cent.	Per cent.
Nickel	40·938	31·35
Copper	45·714	48·86
Iron and (Al_2O_3)	0·405	0·81
Cobalt	0·136	..
Sulphur	11·960	..

It is unnecessary to give a history of the metallurgy of nickel, but it may be well to state that Chronstet isolated the metal in the year 1751, and that Bergman confirmed his discovery in 1774. The methods hitherto employed for extracting the metal from its ores are very complicated; they have involved concentrating the nickel either as a sulphide (matte or regulus), or as arsenide (speise) followed by either "dry" or "wet" treatment. In the case of certain ores, wet methods only have been employed. The metallic nickel has always to be subjected to a process of refining, mainly, as in the case of cast iron, with a view to separate it from associated carbon.

As regards the process which forms the subject of this Paper a few brief historical details may be offered. In 1889 Dr.

Ludwig Mond, F.R.S., in collaboration with Dr. Carl Langer, was engaged in working out a method for eliminating the carbon-monoxide from gases containing hydrogen[1] which they wanted for use in their gas battery.[2] In attempting to effect this, they were guided by the observation they had previously made that finely divided nickel has the remarkable property of removing carbon from carbon-monoxide at a temperature of 350° C., converting it into carbon-dioxide, while the dissociation of carbon-monoxide by heat alone, according to Victor Meyer and Carl Langer, remains incomplete at the high temperature of 1,690° C. In the course of these experiments, which they carried out in conjunction with Dr. Friedrich Quincke,[3] finely divided nickel, formed by reducing nickel oxide at 350° C. by hydrogen, was treated with pure carbon-monoxide in a glass tube at varying temperatures. In order to keep the poisonous carbon-monoxide out of the atmosphere of the laboratory the gas escaping from the apparatus was ignited. They found to their surprise that while the tube containing the nickel was cooling, the flame of the escaping gas became luminous and increased in luminosity as the temperature sank below 100° C. Metallic spots were, moreover, deposited on a cold plate of porcelain held in this luminous flame, just as spots of arsenic are obtained in applying the Marsh test for that metal. It was also observed that on heating the tube through which the gas was escaping, a metallic mirror was obtained, while the luminosity of the flame disappeared. On examination these metallic deposits were found to be pure nickel. The next step was to endeavour to isolate this curious and interesting nickeliferous compound, by preparing nickel with great care at the lowest possible temperature, and treating it with carbon-monoxide at about 50° C. The amount of the volatile nickel compound in the gases passing through the apparatus was thus gradually increased. The gases issuing from the apparatus were treated with a solution of cuprous chloride to absorb the excess of carbon-monoxide, and in this way a residue of several cubic centimetres of a colourless gas was obtained, containing the volatile nickel compound. By passing this gas through a heated tube the nickel and carbon-monoxide were again separated, and the volume of the carbon-mon-

[1] Ludwig Mond and C. Langer. "Improvements in obtaining Hydrogen," British Patent No. 12,608, 1888.

[2] Ludwig Mond and C. Langer. "A new form of gas battery." Proceedings of the Royal Society, vol. xlvi. p. 296.

[3] Ludwig Mond, C. Langer, and F. Quincke. Journal of the Chemical Society, vol. lvii. p. 749.

oxide thus set free was found to correspond to about four equivalents of carbon-monoxide to one equivalent of nickel. By further improving the method of preparing the finely divided nickel, and by passing the resulting gases through a refrigerator cooled by snow and salt, the investigators at last succeeded in obtaining the new compound in a liquid state, and were able to produce it with facility in any desired quantity.

Nickel carbonyl in its pure state is a colourless liquid boiling at 43° C.; it has a specific gravity of 1·3185 at 17° C., and solidifies at −25° C. into needle-shaped crystals. It is soluble in alcohol, petroleum and chloroform; and it is not acted upon by dilute acids or alkalies. It can be readily distilled without decomposition, but on heating the vapour to 150° C., it is completely dissociated into its components, pure carbon-monoxide being obtained, while the nickel is deposited in a dense metallic film upon the sides of the vessel in which the compound is heated.

After the production of nickel carbonyl had become easy, Drs. Mond, Langer, and Quincke directed their attention to the action of carbon-monoxide on other metals. A series of experiments was made with a view to obtain a similar compound with cobalt, which in its chemical and physical behaviour so much resembles nickel. The experiments gave, however, the unexpected result that, unlike nickel, cobalt will not combine with carbon-monoxide. Experiments were then made with iron, and indications were soon obtained of the existence of a volatile compound of iron and carbon-monoxide; a long time elapsed before this new compound was obtained in a pure state. It was finally isolated in a way similar to that by which the nickel carbonyl had been prepared, and proved to be a somewhat viscous liquid of pale yellow colour.[1] Its specific gravity at 18° C. is 1·4664; and it distils completely without decomposition at 102·8° C. under a pressure of 749 millimetres of mercury. When cooled to −21° C. it solidifies into a mass of yellowish needle-shaped crystals. Its chemical composition is somewhat different from the nickel carbonyl, as it contains five equivalents of carbon-monoxide to one of iron. The liquid compound, to which the name of iron penta-carbonyl was given, undergoes no change when protected from the action of light, but exposure to daylight for several hours in a sealed tube is attended with the formation of gold-coloured, tabular crystals, and carbon-monoxide is evolved, so that the

[1] Ludwig Mond and Carl Langer on "Iron Carbonyls." Journal of the Chemical Society, vol. lix. p. 1090.

pressure in the tube rises considerably. The crystals have, when dried, a metallic lustre, and resemble flakes of gold; they contain two equivalents of iron to seven equivalents of carbon-monoxide. None of the other metals which were submitted to investigation showed indications of combining directly with carbon-monoxide.

The discovery that in a mixture of metals only nickel and iron would form volatile compounds with carbon-monoxide, and that they could, therefore, be separated from the other metals, was sufficiently important to induce Dr. Mond to arrange laboratory experiments with ores containing nickel, cobalt, iron, copper, &c., such as "kupfer-nickel" and "pyrrhotite." The experiments afforded such promising results that apparatus of considerable size, though still well within the limits of the resources of a laboratory, was set up, and in it several pounds of ore could be treated with carbon-monoxide.[1] A patent was also applied for on the 12th August, 1890, which describes the way in which such ores may be treated. It is pointed out that the principal nickel ores which are metallurgically treated contain the nickel in combination with arsenic and sulphur besides other metals and gangue. These ores have first to be submitted to the process of calcination, in order that the nickel may be present in the form of oxide, and to drive off, as far as is practicable, the arsenic, sulphur, and other volatile bodies. The resulting oxide of nickel is treated with reducing gases, such as water-gas or producer-gas, in order to convert the oxide of nickel into finely divided metallic nickel; the material containing it then is cooled to about 50° C., and is treated with carbon-monoxide. In dealing with nickel ores which contain nickel oxide in chemical combination with silicic acid, arsenic acid, or other substances which cannot be removed by calcination, the ores are so treated as to convert the nickel into nickel speise or nickel matte, which is then subjected to calcination.

In 1892 an experimental plant on a large scale was erected at Smethwick, near Birmingham. After some years of patient work, during which the plant had several times to be reconstructed, in order to meet all the conditions of this somewhat delicate process, the plant gradually assumed the shape shown in Figs. 1, Plate 1. Before describing it in detail it will be well to give a brief account of the operations involved in the process, which are the outcome of many years of practical experience.

[1] Ludwig Mond on "Metallic Carbonyls." Proceedings of the Royal Institution, vol. xiii. p. 668.

The process is more especially suitable for the extraction of nickel from ores which contain copper in addition to nickel and iron. These ores, which have on an average between 2 per cent. and 6 per cent. of nickel and about the same amount of copper, are first subjected to "heap roasting," to eliminate the greater part of the sulphur, and to convert the iron which forms their chief constituent into oxide. The roasting is necessary to enable the iron in the following operation of smelting to combine with the silica present in the ore to form a slag, and thus to effect the separation of the iron from the nickel and copper which unite with the remainder of the sulphur to form a regulus or matte. This matte contains the nickel and copper in a more concentrated form, the amount of each metal being usually 15 per cent. to 20 per cent., the residue consisting mainly of sulphur and iron. To concentrate the nickel and copper still further, the matte is "Bessemerized." A sample of such "Bessemerized" matte is exhibited; it contains 31·37 per cent. of nickel, 48·62 per cent. of copper and 0·70 per cent. of iron. It was prepared by the Canadian Copper Company, Sudbury, Ontario, from their ores, which contain an average of 4 per cent. of nickel and 4 per cent. of copper. This "Bessemerized" matte is crushed, ground, and subjected to a calcining operation so as to convert the sulphides into oxides, and it is then passed through a mill and dresser. This calcined Bessemer matte then consists practically of nickel oxide and copper oxide in varying quantities. It has been found in the practical working of the process to be advantageous to further concentrate the nickel by extracting part of the copper at this stage by treating the mixtures of oxides with dilute sulphuric acid, which dissolves about two-fifths of the copper present without taking up more than 1 per cent. to 2 per cent. of the nickel. The copper thus dissolved is in the form of copper sulphate and is obtained in a marketable form by crystallization. The undissolved residue from this operation contains between 45 per cent. and 60 per cent. of nickel, and after drying it is subjected to a carefully regulated reducing process by means of water-gas, after which it is treated with carbon-monoxide to extract part of the nickel present. In this first treatment with carbon-monoxide about two-thirds of the nickel can be easily extracted; after this amount is volatilized the extraction becomes much slower, so that it has been found advantageous to recalcine the residues and repeat the copper extraction, the reduction, and the nickel extraction.

The five operations involved are diagrammatically illustrated in *Fig. 2*. The process begins, as will be seen, at one

end with the material to be treated, "Bessemerized" matte; it ends with the market product nickel. The "Bessemerized" matte proceeds, as the arrow indicates, to the first operation (1) of dead roasting, and for this purpose any suitable furnace may be employed. After roasting, the matte contains 35 per cent. of nickel, 42 per cent. of copper, and about 2 per cent. of iron.[1] It then passes to the second operation (2) for the extraction of part of the copper (about two-thirds) by sulphuric acid, the copper being sold as crystallized sulphate of copper. The residue from this process contains about 51 per cent. of nickel and 21 per cent. of copper, and passes to the third operation (3) for reducing the nickel and incidentally the remaining copper, to the metallic state, care being taken to avoid reducing the iron. This is effected in a tower provided with shelves, over which mechanical rabbles pass, the reducing agent being the hydrogen contained in water-gas. The temperature does not exceed 300° C., and should be kept lower when much iron is present. From this tower the ore is conveyed continuously to the fourth operation (4) of volatilization, in which part of the nickel is taken away by carbon-monoxide and forms the com-

Fig. 2.

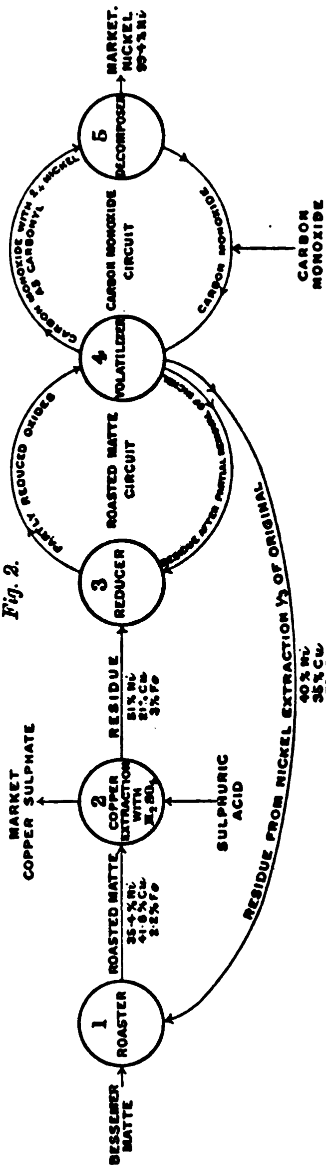


DIAGRAM ILLUSTRATING THE FIVE OPERATIONS INVOLVED IN THE MOND PROCESS.

[1] Average results are given in the *Fig.* rather than the best which have been obtained.

pound nickel carbonyl. The formation of this volatile compound is effected in a tower similar to the reducing tower, but the temperature is much lower, and does not exceed 100° C. From the volatilizer, the ore is returned to the reducer (3), and it continues to circulate between stages (3) and (4) for a period varying between 7 days and 15 days, until about 60 per cent. of the nickel has been removed as nickel carbonyl. The residue from this operation, amounting to about one-third of the original calcined matte, and not differing much from it in composition, is returned to the first operation and then naturally follows the same course as before. The nickel carbonyl produced in the fourth operation, passes to the decomposer (5). This appliance is either a tower or a horizontal retort, which is heated to a temperature of 180° C., so as to decompose the nickel carbonyl and release the nickel in the metallic form, either on thin sheets of iron or, preferably, on granules of ordinary commercial nickel. Carbon-monoxide is also released, and is returned to the volatilizer to take up a fresh charge of nickel. It will be evident that, when the operation is in progress, the gaseous carbon-monoxide and the partially reduced oxides of nickel and copper are continuously revolving in two separate circuits which join and cross each other in the volatilizer (4). The commercial product contains between 99·4 per cent. and 99·8 per cent. of nickel.

It will now be possible to proceed to a description of the working as the Author saw it in full operation in Smethwick a few months ago. The details are clearly indicated in the plan of the works, Figs. 1, Plate 1. The material under treatment during the Author's visit was of Canadian origin, and had been received as calcined Bessemer matte containing 35·4 per cent. of nickel, 41·8 per cent. of copper, and about 2 per cent. of iron. This material was first passed through a ball mill and dresser with a sixty-mesh riddle, and was then treated in quantities of 3 cwt. in a small lead-lined mixer with 200 lbs. of ordinary sulphuric acid, which had previously been diluted with about 20 cubic feet of mother liquor from previous operations. These appliances are shown in the right-hand portion of the plan and elevation, Figs. 1. The temperature of the mixture soon rises by the action between the copper oxide and the sulphuric acid, and is kept, by means of a steam-jet, at a temperature of about 85° C. for ½ hour. From this mixer, the charge is run out into a centrifugal hydro-extractor, provided with a filtering cloth, in which the solution of copper sulphate is separated from the solid residue containing

the nickel. After the filtration of the charge is finished, the speed of the hydro-extractor is increased, and the residue is thus rendered sufficiently free from the liquor.

The solution containing the extracted copper runs from the hydro-extractor into a well, from which it is pumped into the crystallizing vats shown in the Figs. After a period of about 8 days to 10 days, the crystals of copper sulphate are taken out of the vats and the mother liquor is mixed with fresh acid and is again used for the extraction of copper. As already mentioned, a small amount of nickel and a little iron are also dissolved in the sulphuric acid during the copper extraction, so that the mother liquor from which the copper sulphate has crystallized becomes gradually contaminated with these two metals. It is therefore necessary to replace some of the mother liquor from time to time by fresh water, and to recover the nickel from the solution. The simplest method is to evaporate the solution to dryness and to roast the nickel and copper sulphates so obtained. The oxidized material is again introduced into the main process. The copper sulphate crystals from the crystallizing vats are charged into a second hydro-extractor, where they are washed with a little clean water to remove all acidity; they are then dried and are ready for packing. The copper sulphate thus obtained is sufficiently pure for the market, as it contains only 0·05 per cent. of nickel and 0·048 per cent. of iron.

The residue from the copper extraction is taken from the hydro-extractor and stored in a bin until a sufficient quantity has been collected to make up a charge of 5 tons to 6 tons for the nickel-extracting plant. It now contains 52·5 per cent. of nickel, 20·6 per cent. of copper, and 2·6 per cent. of iron. The material is charged by hand at the rate of ½ ton per hour into a feeding-hopper, described as the matte inlet in the lower part of the plan, Figs. 1, Plate 1, which communicates, through a rotary valve, with the conveyor, consisting of a tube enclosing a revolving spiral, which transports the material to an elevator. This lifts the material to the top of the reducing tower, and discharges it through another rotary valve into this reducing tower.

The reducer and the volatilizer (shown in the centre of Figs. 1) in which the treatment with carbon-monoxide takes place, are fully described in Dr. Mond's patent (No. 23,665 of December 10th, 1895). The reducer consists of a vertical tower about 25 feet high, containing a series of shelves, which are hollow so as to admit of their being raised to a temperature of 250° C. by producer gas. The roasted matte falling on these shelves from above is

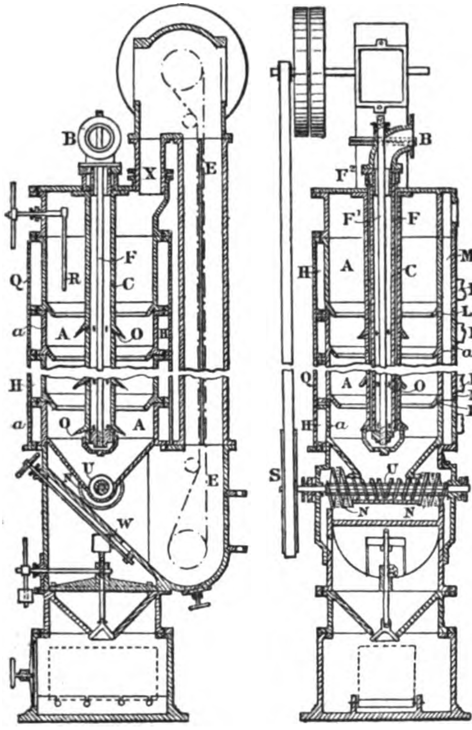
stirred and made to descend from one shelf to that below it by rabbles actuated by a central vertical shaft. Water-gas passes up the tower to effect the reduction of the material. There are about fourteen of these shelves or trays in the tower. The five lower shelves are not heated by producer gas, but are cooled by a stream of water in order to reduce the temperature of the roasted and reduced matte to the temperature at which the volatilizer is worked.

The volatilizing tower resembles the reducer, but the shelves are not hollow, as there is no necessity to heat them. The reduced nickel requires a temperature of only 50° C. to enable it to combine with carbon monoxide and form a volatile compound, and the matte and gas are sufficiently hot to maintain this temperature. In the plant at Smethwick the volatilizer was made the same size as the reducer, but in the new plant it is somewhat smaller.

The decomposer has been devised with much care, and has, in its present form, only recently been patented. The nickel is deposited in it, from its gaseous compound with carbon-monoxide, on granules of ordinary commercial metal. The arrangements by which this is effected are very ingenious, and may be described almost in the words of Dr. Mond's latest patent. The object is to obtain metallic nickel from nickel carbonyl in the form of pellets, which are specially suitable for the production of nickel alloys. For this purpose gases containing nickel carbonyl are passed through granulated nickel, which is kept at the temperature required for the decomposition of the carbonyl—about 200° C. The nickel which thus separates from the carbonyl becomes deposited on the granulated nickel, which consequently increases in size. In order to prevent cohesion of the granulated nickel, it is kept in motion. When a number of the pellets have attained a convenient size, they are separated by sifting without interrupting the depositing operation, the smaller granules being returned to receive a further deposit from the nickel carbonyl. A convenient form of apparatus for effecting the process described is shown in *Figs. 3*, which represent vertical sections of the apparatus on planes at right angles to each other. A is a cylindrical vessel, preferably built up of short cylinders, *a a*, bolted together; it contains a central tube, C, provided with gas outlet holes, O, through which the gas containing nickel carbonyl, entering at the gas inlet, B, passes into the vessel which is filled with shot, or small granules, of nickel. The gas permeates through the interstices between these granules, and is brought into intimate contact with them, and when the nickel carbonyl is decomposed, the nickel is deposited

on the granules. The gases finally escape through the outlets, L, into the gas-exit pipe, M. In order to prevent the granules from cohering, they are kept slowly moving by continuously withdrawing some of the granules from the bottom of the cylindrical vessel, A, by means of a right- and left-handed worm conveyor, U, which delivers the granules into two sifting-drums, N. The smaller granules fall on to the inclined plane, W, and collect at

Figs. 3.



VERTICAL SECTIONS THROUGH THE DECOMPOSER.

the base of the elevator, E, which conveys them again to the top of the cylinder, A, and feeds them through the feeding-hole, X. In order to avoid the deposition of nickel from the nickel carbonyl in the central tube, C, it is kept cool by causing water to circulate down the tube, F, and up through passages, F^1, formed in the central tube, to the water outlet, F^2. The cylindrical vessel, A, is surrounded by a wrought-iron casing, Q, which forms heating-spaces, H, communicating with heating-flues, P, which are so

arranged that the temperature of each cylinder can be separately regulated by dampers, so as to maintain the temperature of the granules of nickel contained in the vessel, A, at about 200° C., at which temperature the nickel carbonyl is decomposed. With a view to ascertain whether the cylinder, A, is full of granules, a rod, R, is fixed to the spindle of an external handle, which can be turned partly round, so that if the operator feels resistance to the motion of the R, it is certain that the granules extend to that height. The appliance used for depositing the nickel originally consisted of a series of retorts lined with thin steel sheets, on which the nickel was deposited in layers. It was found, however, that the metal so obtained was very difficult to cut, and the apparatus above described was accordingly devised.

Fig. 4.

PHOTO-MICROGRAPH OF A GRANULE OF NICKEL, MAGNIFIED THREE DIAMETERS.

A magnified section of a granule of nickel, which was about $\frac{3}{4}$ inch in diameter, is shown in *Fig. 4.* It will be seen that there is a core of nickel which under higher magnification shows a crystalline and convoluted structure, and this core is surrounded by concentric layers. The central core is ordinary commercial nickel, and the layers are nickel deposited from its carbonyl. In some cases granules of deposited nickel are found without any central core. These have grown from minute fragments of deposited nickel which have become detached during the course of deposition.

The water-gas used in the reducer is generated in gas-producers, three of which are shown on the left of the plan, Fig. 1, Plate 1 Anthracite is used to decompose the steam, and the water-gas is collected in a gas-holder, whence it is taken to the reducing tower, to which reference has just been made. This gas contains, on entering the reducer, about 60 per cent. of hydrogen.

The reducing operation is so regulated that only a small quantity of hydrogen remains in the escaping gas, as a rule not more than 5 per cent. to 10 per cent. This waste gas is subjected to the action of a fine water-spray (not shown in the Fig.), which

condenses the steam generated by the combustion of the hydrogen in the water-gas. Part of this waste gas is used for making the carbon-monoxide required in the volatilizer, by passing it through the CO retort charged with incandescent charcoal, Fig. 1, which reduces the carbon-dioxide contained in the waste gas, and this increases the amount of carbon-monoxide in it. The gas issuing from this retort contains about 80 per cent. of carbon-monoxide, and is stored in another gasholder, which communicates with the main circuit of the carbon-monoxide gas. This main circuit of the carbon-monoxide passes through the volatilizer already referred to, where the nickel is taken up. The carbon-monoxide, now charged with nickel, passes through a filter to separate the fine particles of matte-dust from the gases, then through an apparatus called the decomposer, and so described in the figure. In this decomposer the nickel taken up in the volatilizer is deposited. The gas now deprived of its nickel passes to the CO blower, Figs. 1, which sends the carbon-monoxide to the volatilizer in order that it may take up a fresh charge of nickel.

The solid material from which the nickel is being extracted is kept circulating through the reducer and volatilizer for a period varying between 7 days and 15 days, during which time the oxides are gradually reduced to the metallic state and the nickel volatilized. When the material originally charged in has had the bulk of its nickel extracted it is run out through a rotary calciner roaster, Figs. 1, which converts the metals into oxides, so that they may be treated for the second time with sulphuric acid and carbon-monoxide. The ratio between the nickel and copper in the residues from the nickel extraction is practically the same as in the calcined Bessemer matte, with which the operations were started, but the amount of iron has increased by the removal of the copper and nickel, as the following figures show:—Original matte contains, nickel, 35·27 per cent., copper, 41·87 per cent., iron, 2·13 per cent. After the first treatment of copper and nickel extraction, the quantities are, nickel, 35·48 per cent., copper, 38·63 per cent., iron, 4·58 per cent.; and after the second copper and nickel extraction, nickel, 35·83 per cent., copper, 35·56 per cent., and iron, 7·82 per cent. The amount of nickel extracted in these two cases was, after the first treatment 61 per cent., and after the second treatment 80 per cent. of the nickel present in the original matte. It must be remembered, however, that in the second treatment only one-third of the original amount remains to be treated, while the final residue is only one-tenth. To avoid the formation of iron carbonyl, the temperature in the

reducer has to be kept very low, and if this is done, the nickel extracted from a matte originally containing as much as between 6 per cent. and 10 per cent. of iron will not contain more than 0·5 per cent. of iron. If the amount of iron in the residues rises above this percentage, the extraction of the nickel is very much delayed, on account of the low temperature which must be maintained in the reducer. It is necessary, in such a case, to re-smelt the residues before proceeding with the extraction of the nickel and copper. The following are analyses of the deposited nickel:—

—	I.	II.
	Per cent.	Per cent.
Nickel	99·82	99·43
Iron and (Al_2O_3)	0·10	0·43
Sulphur	0·0068	0·0099
Carbon	0·07	0·087
Insoluble residue	..	0·026

The experimental plant at Smethwick has been working for some time, and about 80 tons of nickel have already been extracted in it from different kinds of matte. The results obtained were quite satisfactory, and they point to the conclusion that the process is fully able to compete with any other process at present in use for the production of metallic nickel.

By the kindness of Dr. Mond, the Author is able to exhibit plans for a large manufacturing plant, and Figs. 5, Plate 1, show a vertical elevation, sectional plan and cross-section of it. This plant will, it is estimated, produce 1,000 tons of nickel per year. The plant is so arranged that the matte is continuously charged into the first reducer and traverses the whole set of appliances. When the matte issues from the last volatilizer the first nickel extraction is finished. The matte is re-roasted and submitted to the second copper and nickel extraction. There are ten appliances, consisting of one large reducer, eight combined reducers and volatilizers, and one large volatilizer. They are so arranged that the matte has first to pass through the large reducer, and is then lifted, by means of an elevator and conveyor, into a volatilizer (erected on the top of the next reducer). The relative positions of the reducers and volatilizers are best shown in the cross section, Figs. 5. It passes through the volatilizer into the upper portion of the reducer and in traversing this it is further reduced. It is then lifted again to the next volatilizer, and so on till it finally reaches the larger volatilizer

at the end of the whole series, and, after passing through this, it is discharged into the roasting furnace. The conveyor on the top of the volatilizers into which the elevators discharge, is common to the whole set of volatilizers and reducers, so that, in case any portion of the plant has to be disconnected, the rotary valve through which the material is discharged from the conveyor into the volatilizer is stopped. The material then passes on through the conveyor into the next volatilizer. The two gases, carbon-monoxide in the volatilizers and water-gas in the reducers, are kept separate by rotary valves of the same construction as in the small plant. The water-gas connections are so arranged that each reducer receives fresh gas from the main, with the exception of the first large reducer, through which the waste gas of all the other reducers is passed, so as to burn completely all the hydrogen in the water-gas. The carbon-monoxide passes through the volatilizers from a common main, and is collected, after it has passed through the filters, in a main leading to the blower. From the blower the carbon-monoxide charged with nickel passes through a set of decomposers, and again into the main which feeds the volatilizers.

With regard to the application of steel containing between 1 per cent. and 7 per cent. of nickel in constructive work, the Author need not remind members of the Institution of the importance of nickel steel not only for the manufacture of armour-plates but for all purposes where strength and lightness are essential. One manufacturer in the United States used in 1 year no less than 178 tons of nickel in the form of nickel steel, and it has been stated by a competent authority that "if propeller shafts were made of nickel steel the question of failures would seldom or never be raised." An attempt to deal adequately with the application of nickel would lead far beyond the scope of the present Paper, and the Author only adds that the extraordinary properties of these alloys have formed the subject of elaborate investigations by the late Dr. John Hopkinson[1] and by Mr. Guillaume.[2]

The Author acknowledges his indebtedness to Dr. Mond and to Dr. Langer for enabling him to examine the Smethwick Works in detail and for the drawing they prepared for him of the plant. The Author's assistant, Dr. Stansfield, was by Dr. Mond's kindness

[1] Proceedings of the Royal Society, vol. xlvii. p. 23; vol. xlvii. p. 138; vol. xlviii. p. 1.

[2] Comptes rendus, vol. cxxiv. pp. 176, 752 and 1515, and vol. cxxv. p. 235.

able to watch every stage of the process during a prolonged visit to the Works.

It will have been evident that the process possesses unusual interest as being the only one, in the whole range of metallurgy, in which a metal is obtained from its ores by causing it to combine with a gas to form a gaseous product from which it is subsequently released. Not the least remarkable feature of the process is presented by the fact that the temperature at which the whole operation is conducted never exceeds 300° C., which is far below dull redness. As a consequence, the plant, which may still admit of simplification, is not, as is usually the case with metallurgical appliances, subjected to alterations of temperature extending through a considerable range. The repairs needed are therefore inconsiderable, and the amount of fuel required is but small. The process works more or less automatically, and the amount of labour involved in conducting it can be reduced within very narrow limits. The main operation is, moreover, a regenerative one; the carbon-monoxide moves in a cycle and is the vehicle for continuously transferring the nickel from the ore or matte, and converting it into a marketable form. It follows that in the extraction of the nickel no new material except the reducing agent, water-gas, has to be introduced into the system. This is true even of the granules of commercial nickel which fill the decomposer and serve as a basis for the deposition of the nickel from the carbonyl. Their presence is essential in starting the process; but their place is, as has already been pointed out, gradually taken by fragments of the deposited metal which becomes detached as the operation proceeds. The process will always occupy a prominent place in chemical history, and there would seem to be no reason why it should not play an important part in metallurgical practice.

As regards the application of the process in Canada, the Author trusts that this attempt to make it better known may contribute to develop one of the resources of the great Dominion.

The Paper is accompanied by six drawings and a photomicrograph, from which Plate 1 and the Figures in the text have been prepared.

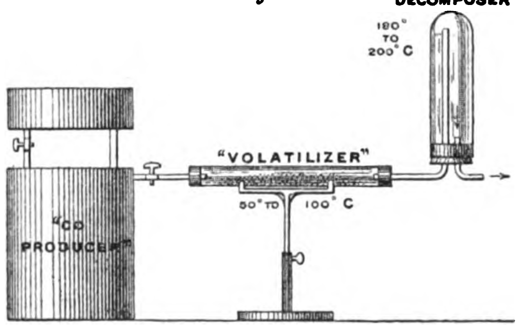
Discussion.

Mr. W. H. PREECE, C.B., F.R.S., President, said it was his first duty to propose, and he was sure it would be carried with acclamation, a vote of thanks to the Author for the extremely clear and able way in which he had brought before the members a process that appeared to be new from beginning to end. It was one which they would watch with great interest and hope to have further light thrown upon. To many it was startling to think that nickel could be converted into a gaseous form, and from the gas the solid metal that was so much required extracted by moderate increase of temperature. Mr. Preece.

Prof. ROBERTS-AUSTEN, C.B., remarked that as the process was of such great interest to Canada, he might be permitted to read a telegram he had received from Lord Strathcona and Mount Royal, the High Commissioner for the Dominion:—"I am exceedingly sorry that owing to a severe cold I am compelled to deny myself the pleasure of being with you this evening. Your address would have had great interest for me, seeing how important the nickel industry is to Canada. Please accept my sincere regrets." He would first call attention to the liquid carbonyl compounded of carbonic oxide and iron. A sample was exhibited, for which the Institution was indebted to the kindness of Dr. Mond, together with a sample of the fluid carbonyl of nickel; but it was so poisonous that he feared to leave it where the tube in which it was contained might become fractured. He desired to show the actual experiment upon which the whole beautiful process was based, but it was an exceedingly delicate one to bring from a laboratory and show in a room far away from the place in which it had been arranged. The gasholder contained carbonic oxide, and a little of the gas was ignited to show that it burnt with the characteristic flame of that gas. This gasholder, *Fig. 6*, corresponded with the carbonic oxide retort of Figs. 1 and 2, Plate 1. The gas was then passed over finely divided metallic nickel at a temperature not necessarily exceeding 50° C., and the luminosity of the flame was materially increased. The tube containing the nickel corresponded with the portions of the plant called "volatilizer" in Plate 1. In a very few minutes the carbonic monoxide took up its charge of nickel, and there was a luminous flame which deposited its nickel on any cold surface held over it. The Prof. Roberts-Austen.

Prof. Roberts-Austen. flame was fully charged with nickel and deposited a black layer of the metal on a plate of cold porcelain. It could be seen within what a very small range of temperature the whole operation was conducted. By passing the gas into a tube, and by heating it, a brilliant deposit of metallic nickel was obtained on the inside, in the form of a mirror. This tube corresponded with the "volatilizers" of the plant shown in Plate 1. The plate of solid nickel, which he exhibited, stripped off a sheet of iron on which it had been deposited, was prepared precisely as shown by the experiment, only in a large retort. He also exhibited granules of nickel having a core of ordinary commercial nickel. If the nickel carbonyl was introduced into an ordinary non-luminous Bunsen burner it instantly became luminous. Photographs were projected upon the screen to illustrate (1) the roasting bed of the great ore deposit

Fig. 6.



in the district near Sudbury; (2) a mass of nickeliferous regulus resulting from the process of heap roasting, showing on what a grand scale the operation was now conducted; (3) a magnified granule of ordinary commercial nickel surrounded by concentric layers of nickel, *Fig. 4.* The central core was unduly large. In conducting the process on the large scale, no new granules had to be introduced into the system, because the fragments of the external layers became detached and so served as a basis for the deposition of fresh quantities of nickel from the carbonyl; (4) an enlarged view of a granule showing the crystalline structure of the ordinary commercial nickel, which contained carbon, while the banded layers were magnifications of the pure nickel deposited on the nucleus of commercial nickel; and (5) heating and cooling curves of metallic nickel registered by means of an autographic pyrometer. As the nickel attained a temperature of 600° C. there was a distinct

break showing absorption of heat; and conversely, as the metal cooled there was a slight elevation corresponding in position with that on the other side, which meant that as the metal cooled there had been true recalescence, exactly as in the case of iron. The points in the curve were not in any way due to carbon, but to the molecular change in the nickel itself. Another bond of union was thus demonstrated between metallic iron and metallic nickel, which in many ways resembled each other. Prof. Roberts-Austen.

Dr. LUDWIG MOND desired to express his gratitude to the Author for having introduced, in so lucid and eloquent a manner, his invention to the Institution. It had required very careful tending, but he thought it was now quite capable of taking care of itself in the struggle for independent existence among manufacturing processes. When the Author had first suggested that he should like to bring the subject before the Institution, Dr. Mond had some difficulty in seeing the connection between nickel extraction and the Institution of Civil Engineers; but having enjoyed the privilege of listening to the beautiful address delivered by the President a week before, he had learnt how many different kinds of engineers were admitted to the Institution; and he believed he had grasped why the Author was desirous to choose that particular subject for the Paper it had become his privilege and duty to read. He hoped that the Paper, showing as it did the great engineering difficulties that had to be solved to carry out that apparently very simple process of manufacture, would have completely dispelled any doubts as to the position occupied by the chemical engineer in the great fraternity. In his remarkable address the President had made out a very strong case in favour of electricity becoming the exclusive handmaid of mankind, to minister to all its wants. He ventured to think that in future there would still be innumerable occasions on which chemical affinity would be called upon for assistance, and he believed the process described in the Paper would be one of those cases where chemical affinity would successfully resist all attacks by electric currents. It would be noticed how delicate the action of chemical affinity was in that process, how it became completely reversed by slight increase of temperature and how carbonic oxide and nickel combined readily at 100° C. and fled asunder again at 180° C. That was the great beauty of the process and the great facility which it offered to attain the end in view. Dr. Mond.

Colonel JAMES BAKER, late Minister of Mining, British Columbia, was constrained to remark upon the immense importance the experiments that had been shown must have upon the mining Col. Baker.

Col. Baker. interest of Canada generally. It was known that the nickel ores experimented upon by Dr. Mond had been all derived from the Sudbury district in Ontario. He was very anxious, if possible, to find the province of British Columbia possessed of nickel ores somewhat similar to those of Sudbury, and he had issued instructions to the various mining recorders in different parts of the province to send to the Government assayer all the ores they possessed, in order that they might be tested for nickel; but he regretted to say they had not yet succeeded in finding it in any marketable quantity. However, a large body of ore had recently been discovered in Vancouver Island, similar to the ore which was, perhaps, familiar to some of the members present under the names of chaleopyeites, and somewhat similar to that at Rossland; but there was a difference, in that it contained a little more nickel and a considerable amount of gold. Therefore, he hoped that, by further experiments with ores in British Columbia, a quantity of nickel that might be of marketable value might yet be arrived at; if so, he was quite sure he might look forward to its being treated by the wonderful process which had been explained by the Author. It must be remembered that British Columbia was a young province, and that the discovery of lode mines there was, comparatively speaking, of recent origin, and that it also took a considerable amount of time and capital to develop the mines. If the mines had not been brought to a remunerative basis more quickly it was because of the time and capital necessary for that process.

Mr. Stead. Mr. J. E. Stead observed that Dr. Mond's wonderful discovery had been known for some time to chemists, who had thought it impossible to make a practical process for the manufacture of nickel by it; but they also thought, at the same time, that if there was one man in the world who could do it, it was Dr. Mond himself. The process was a wonderful monument to Dr. Mond's chemical and engineering skill, for the elaboration and the skill which had been shown in the arrangement and the design of all the machinery to conduct the special process was very remarkable, and reflected enormous credit upon Dr. Mond and his fellow-workers. The Paper also reflected credit upon the Author for its great lucidity and clearness. Those who had studied the calcining of nickel ores would know the great difficulty of eliminating the sulphur, which seemed to be a great trouble in the present case. The sulphur adhered to the nickel very persistently, and the nickel must be in the state of oxide before it could combine with carbonic oxide; more information upon this point would

therefore have been interesting. Again, after the first and second roasting processes, he should like to know why the copper and nickel remained in a definite ratio. Was some union formed between the nickel and copper? and why should the nickel refuse to give itself up in the presence of the particular quantity of copper referred to in the Paper? He thought the process a marvellous one to be conducted at such an extremely low temperature. It was certainly a new departure, first obtaining the metal in the form of gas at relatively an extremely low temperature and then depositing it at 200° C., below the melting-point of tin. It was possible that for a time the process might be in the ordinary stage of infancy; but eventually, he hoped and believed, that, with Dr. Mond's skill and wonderful ingenuity, it would be, if it were not already, a practicable and valuable one for the manufacturer of nickel. Mr. Stead.

Mr. GEORGE ATTWOOD had acted for some years as Consulting Engineer to the Dominion Mineral Company, the next company in importance to the Canadian Copper Company, and had designed and constructed all their mining and smelting works. He agreed that the production of metallic nickel in the Sudbury district was disproportionate to the extent of its mineral deposits. The lack of a refining process that could be worked economically on the spot had been one of the chief reasons why the Sudbury nickel deposits had been neglected. The mining companies, after converting the ores into a matte or regulus, had then to sell to the refiners in America, England, and on the Continent. Their agents had sometimes received 1*s.* per lb. for the nickel in the matte, and in some cases only 7*d.* per lb. in mattes containing 25 per cent. of nickel, and 15 per cent. to 20 per cent. of copper. In 1891 he conducted a series of experiments by the Mond process. The first trial was made on crude ore, which contained about 3·35 per cent. of nickel, and 1·70 per cent. of copper. After several days' treatment, the quantity of nickel obtained was so small that the experiments on that class were abandoned. He then decided to make a trial on matte containing about 25 per cent. of nickel and 14 per cent. of copper, and about 0·65 per cent. of cobalt. After dead roasting, the matte was treated as before, with much better results. The nickel obtained was free from cobalt, the separation of which was important in these ores. It was free from cobalt, although the matte contained 0·65 per cent. of it. The extraction of the nickel was very slow in his experimental plant. Finally he experimented with richer matte, containing nearly 40 per cent. of nickel, and 43 per cent. Mr. Attwood.

Mr. Attwood. of copper and an unestimated amount of cobalt; the results were very good. Those experiments had been made on a small scale, a few pounds of ore for a special purpose. He was hopeful that the ore could be treated after it had been received from the mine, first roasting it, and then treating it direct by the Mond process; but he found that that was not possible, and so the experiments were abandoned. He had no doubt that the Mond process would work well on the Sudbury mattes. He would be interested to have a comparative estimate of the cost of a plant which would treat, say 3,000 tons of matte per annum, producing about 1,000 tons of nickel. He would also like to know the cost of working the plant, on either per pound of nickel or per hundredweight of nickel produced. He had been more or less concerned in the nickel and cobalt industries all his life, and he considered the process described the most important advance made during his lifetime.

Mr. Hadfield. Mr. R. A. Hadfield thought that, in view of the great interest now attaching to the use of nickel, the Paper would be more complete if information were given with regard to the cost of production. At present the prices were exceedingly high, reaching £120 to £140 per ton. He believed there was a very promising future for nickel steel. When ferro-manganese with 70 per cent. or 80 per cent. of manganese began to be used, £100 a ton was paid for it, and the consequence was that it was adopted only on a small scale. He thought the sooner the price was brought down to a moderate rate, the more quickly would the use extend. It was a great mistake to overdo high prices of these special metals. He was aware that the price of nickel had already fallen very considerably, as it was not many years ago since *5s. 6d.* per lb was paid. The very admirable process which had been described should effect a further reduction in the cost of production. He believed that in Canada there were other sources of supply beside that of Sudbury. A well-known mining engineer from Canada had informed him that several large deposits were now being prospected. It was singular that Canada seemed to possess a very large part of the nickel ores of the world, and he was glad they were on British soil, especially at the present time when armour plates were a subject of such great interest. He had had put before him a certain quantity of Mond nickel and nickel made by the ordinary method, and he had produced an alloy of nickel steel with the two metals, one made by the Mond process, and the other by the ordinary process, and sold by the Orford Copper Company. He

was pleased to say that Dr. Mond's metal gave steel of very high quality. The Mond nickel gave an elastic limit of 24 tons, with a breaking strength of 36 tons, elongation of 32 per cent., and a reduction area of 56 per cent. The material made from the Canadian Copper Company's nickel gave an elastic limit of 23 tons, a breaking load of 35 tons, elongation 27 per cent., and reduction in area 49 per cent.—not quite equal to the last result. On analysis, the steel contained 0·25 per cent. of carbon in the Mond product, and 0·26 per cent. in the other one; 0·06 per cent. and 0·05 per cent. respectively of sulphur; 0·04 per cent. of phosphorus, 0·75 per cent. each of manganese, and 2·9 per cent. each of nickel. They afforded an excellent comparison, and were very uniform in chemical composition. He also had an analysis prepared of the two metals, and the Mond nickel was certainly slightly purer. The length upon which the elongations had been measured was 2 inches, with an area of 0·5 square inch. He had also made a series of tests on a ½ square inch area, and the results were very similar. Steel makers wanted to obtain the best possible product, and were very glad to see a high-class material in the market such as had been described by the Author. There was not a very large difference—about 1 per cent. in the nickel, and the carbon in the Mond metal was about half that in the other. In neither case was it high—about 0·16 per cent. and 0·05 per cent. There was also a little more iron in the Canadian Copper Company's nickel. He hoped the new development would add largely to the wealth and increasing prosperity of Canada. Mr. Hadfield.

Mr. J. Bernays had been employed to design and erect the original Smethwick plant under the instructions of Dr. Mond, and he greatly admired the beauty of the whole process produced by a few simple mechanical appliances such as cylinders, elevators, grinders and furnaces. The whole apparatus seemed to be working at moderate heat from morning to night, ore going in at one end and nickel coming out at the other. The plant illustrated appeared to be considerably changed from that originally designed, and he noticed that the decomposer had been entirely altered from what it was in the first instance. But such very important inventions always required a considerable number of alterations before the apparatus was brought to perfection. Mr. Bernays.

Sir Frederick Bramwell, Bart., Past-President, remarked that, having just seen the interesting experiment of the deposition and solidification of nickel out of its condition as a component of a gas, at a temperature of 200° C., he should be glad to know at what temperature solidification took place, when nickel was in the Sir Frederick Bramwell.

Sir Frederick Bramwell. metallic state and had been fused; in other words, what was the ordinary melting-point of nickel?

Dr. Mond. Dr. LUDWIG MOND pointed out that one of the advantages of the process was that the sulphur need not be completely roasted from the matte in the first instance. The matte was roasted three times, and the sulphur left in at the first calcination was removed by the subsequent ones. There was the very peculiar fact that by attacking the roasted matte with sulphuric acid only a certain amount of copper was dissolved, until a definite relation between nickel and copper was established; still, he did not venture to base any theory on this fact. With regard to the questions asked as to the cost, he might say that he had not come to the Institution to transact business, but if any gentlemen were anxious to know any details about that matter he should be very pleased to reply, if they would send their questions in writing.

Prof. Roberts-Austen. Professor ROBERTS-AUSTEN, in reply to the discussion, stated the melting-point of nickel was 1600° C. He had considered the question of cost with very great care, but he felt it was rather beyond him; he was satisfied, however, that the process would compete favourably with any now in use, and he thought it unfair to draw up an estimate as to cost from appliances which were confessedly in a transitionary state. That was the reason why he did not produce the thoroughly comprehensive figures which were submitted to him, not only by Dr. Mond, but by Dr. Langer. He might add that Dr. Stansfield examined these data with the greatest possible care. It was with much confidence that he expressed his belief in the economy with which the process could be conducted.

Correspondence.

Mr. Gibb. Mr. THOMAS GIBB, of Liverpool, pointed out that keeping all the appliances for the treatment and circulation of the materials and gases rigidly enclosed would entail much skill in the construction and care in the working of the apparatus; this was made comparatively easy by the extremely low temperatures at which the operations were conducted compared with the temperatures usually employed in metallurgy. The Author could not have done a better service to metallurgy than bring before the Institution this unique process, now that its initial difficulties had been patiently and, to all appearance, successfully combated, and it was likely to be launched as an important industrial operation.

The process, worked on a large scale, involved a large production of sulphate of copper. For instance, the 1,000-ton plant contemplated would have to be accompanied by plant for the production of 4,500 tons of crystallized sulphate of copper, and any general adoption of the process would entail a formidable competition with existing works. The copper could be precipitated either by iron or electrolysis; but, however it was performed, the plant for, and cost of, its utilization would have to be reckoned with whenever its quantity became too large to be advantageously placed on the market as sulphate. Mr. Gibb.

15 November, 1898.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

(*Paper No. 3079.*)

"Electrical Transmission of Power in Mining."

By WILLIAM BEEDIE ESSON, M. Inst. C.E.

IN mining undertakings the disadvantages attendant on expensive transport have recently been to a large extent neutralized by electrical transmission of power. Auriferous quartz is frequently found in regions difficult of access, where the transport of fuel to the mine for the purpose of crushing by steam-power, or conveying the ore to a distant steam- or water-driven mill, would be extremely costly. But these natural disadvantages can be greatly mitigated by the delivery, at the mine, of power transmitted electrically from a distance; and, thus provided, a district traversed by low-grade ore can be made to yield results which, apart from such supply of power, could only be realized if the ore were of rich quality. In several districts the advantages of employing electricity appear to have been completely overlooked, and many properties might have become remunerative at a much earlier date if the benefits which the use of electricity confers had been recognized. There is often abundant water-power, but mills have been built at the river sides, and, in consequence, the great cost of transporting the quartz to the mills has prevented profitable working. By using electrically transmitted power, the mills might have been built at the mines and the rock crushed there, with great saving of expense and certain profit.

The Author does not propose to institute a comparison between electrical and other methods of transmitting power. The matter may be dismissed with the observation that, so far as the

application of power-transmission to mining work is concerned, electricity is generally the only practicable means. The ease with which copper wire can be carried over any kind of country, wherever desired, coupled with the plastic character of the material, renders the electrical conductor the simplest and most reliable of all vehicles for power-transmission; while the induction electric motor is of all machines the least complicated, and, on account of its simplicity of construction, the least likely to suffer serious injury or damage through rough usage. Motors of this kind are adapted for driving stamps, crushers, hauling-gear, pumps, fans, and all the other machinery connected with mining.

As a general rule, before deciding whether power-transmission shall be adopted, it is only necessary to compare the cost of two schemes—(*a*) bringing fuel to a mine to work the machinery by steam; (*b*) transmitting power to a mine electrically from a generating-station situated at some convenient position for utilizing existing water-power. The working expenses added to the interest on the capital invested make up in both cases the annual cost, but it must not be forgotten that the number of hours worked per day constitutes an important factor. The first cost for either scheme depends on the maximum power to be transmitted, and is independent of the hours of working, but it is not so as regards the working expenses. While the cost of water may be merely nominal, fuel must be paid for in some way; and while a comparison of the schemes might show for 12 hours working per day a result in favour of steam, for a 24-hour day the evidence might be largely in favour of water.

The foregoing applies to the usual circumstances under which the choice lies between laying down steam-power at the mine, and electrical transmission to the mine, of power derived from water; but there are cases in which electrically transmitted power with the generators driven by steam may have a good chance of success. The Rand Central Electric Works afford an example of the latter class of installation. The generators are driven by large steam-engines at the mouth of the Brakpan coal-pits, where fuel can be easily obtained at a comparatively low price, the power being transmitted for about 30 miles to mines difficult of access for ordinary delivery of fuel. The cost and difficulty of constantly transporting fuel makes the working-expenses very high, and it is estimated that the average cost to mine owners on the Rand of one steam horse-power per annum is £56 10*s*., taking large and small engines together, and excluding interest and depreciation. It is reckoned

that the total steam-power on the Rand is 21,000 HP., and the Company whose works are referred to has, as a first instalment, laid down plant for transmitting 2,100 brake HP., charging mine owners at the rate of £45 per brake HP. per annum. A general power-delivery scheme of this kind has many advantages over independent steam-plants at individual mines, and several such projects are at present under consideration.

The electrical transmission plant now to be described has been in continuous work at the Sheba Company's mines, Barberton, Transvaal, for more than 2½ years; and, though previous to its being started, electricity had played a not unimportant part, so far as supplying power from steam-driven generators for pumping, hauling, &c., was concerned, there had been no attempt to substitute for the steam-power required for working the heavy machinery, the power of water transmitted from a distance. For what electrical work there was, continuous current machinery was used, whereas the Sheba installation, about to be described, is worked by alternating currents.

The Sheba Mine is situated in the mountainous district of the De Kaap Goldfields, Fig. 1, Plate 2. The first mill was built on Fig-Tree Creek, on a site 3 miles from the mine. It consisted of twenty stamps, and the power was derived partially from the water in the creek and partially from steam generated by wood fuel. The ore was transported from the mine to the mill by ox-wagons. The second mill, a fine battery of sixty stamps, was erected on the Queen's River, and was driven by turbines. The rock was conveyed to the mill by an aerial ropeway, about 2¾ miles long, over the mountains. The ropes were carried on high standards, and long spans were demanded by the conditions of the country. After much trouble and expense this ropeway was brought into excellent working order, but an enormous flood in February, 1895, washed away the dam and the water-race; the mill had to be closed, and there was no further use for the aerial ropeway.

At the date of the flood referred to, a new mill of sixty stamps was being erected upon a site selected as near to the mine as local conditions would allow; and a power-house was being built on the Queen's River at Avoca, 5 miles from the mine, to carry out the electrical transmission scheme. The original plans embraced the supply of power to drive the battery with the vanners, crushers and pumps, and to light the mine. This was to be an experimental plant, and on its success depended further extensions. It had been estimated from gaugings of the river

that there would be in dry seasons enough water to admit of 500 HP. being developed on the turbine shafts. For the requirements at first, the power necessary at the mine was :—

	HP.
For the 60-stamp mill	100
" Vanner room	10
" two crushers	30
" lighting	7
" pumping	15
Total	162

The plant for transmitting this power was installed, and in July, 1895, crushing was commenced. Since that time the Sheba Company has depended solely on electricity as its medium of power for crushing. In this case the mill was situated at the mine, an arrangement that possesses great advantages over the former method, whereby the ore was taken to the mill by ox-wagons or by an aerial ropeway. Apart from the convenience attending the centralization of the work, the following comparison of costs is instructive :—

(1) *Twenty-Stamp Mill, Fig-Tree Creek. Ox-Wagon Transport.*—The working costs for fuel and transport, under favourable conditions, amounted to £1 12*s.* 6*d.* per ton of ore milled.

(2) *Sixty-Stamp Mill, Queen's River. Aerial Ropeway Transport.*—The average working cost for the transport of rock during 1893 and 1894 was 6*s.* 1*d.* per ton of ore milled.

(3) *Sixty-Stamp Mill, Queen's River. Electrical Transmission of Power.*—The average working cost, including supervision, wages, stores, repairs, &c., in July, 1896, was less than 2*s.* per ton of ore milled, and in March, 1897, it had fallen to 1*s.* 8*d.* There is little doubt that when sixty more stamps are at work, the cost will fall to 1*s.* per ton.

It will be seen that the cost is emphatically in favour of electricity, and, based on a monthly average of 4,000 tons milled, under present circumstances the saving to the Sheba Company is over £10,000 per year.

General.—Having taken the opinion of several authorities on the subject generally, Messrs. Davis and Soper, acting on behalf of the Sheba Gold Mining Company, decided that, for the purposes of this work, transmission by alternating currents of two phases through underground cables was the most suitable. This method was adopted as combining the greatest ease of control with the

best regulation for the lighting circuits, and as best adapted to the climatic conditions of the district. The current is generated and carried to the mine at a pressure of 3,300 volts. It is there reduced by transformers to a pressure of 100 volts, and is thence led to the motors and to the lighting circuits.

Hydraulic Works.—The dam for the water-supply existed previously, and is situated 2 miles above the site chosen for the generating-station, measured along the course of the water. It is 430 feet wide, and the water enters the race by four intake gates. It then runs through a deep channel parallel to the river for 800 yards, for 300 yards further it is carried through a tunnel 7 feet 9 inches high by 6 feet wide, thence into another open race 440 yards long, and finally through a short tunnel to the penstock. Considerable trouble has been experienced with the longer tunnel, as the dimensions require the speed of the water to be greater there than in any other portion of the race, and a large amount of shale is washed down. The water has occasionally to be turned out of the race to clear the debris.

The generating-station is built under a deep bank of shale and soapstone, and, to prepare the site, many thousand tons of the bank had to be removed. Owing to the experimental nature of much mining work, there is generally a considerable amount of spare machinery on the fields, and the Sheba Company's engineers determined to use for driving the generators two Victor turbines which were available, one being 30 inches and the other 25 inches in diameter. The maximum fall obtainable is 32 feet, and with this the two turbines are together capable of developing 396 brake HP. at a speed of 232 revolutions per minute for the larger, and 279 revolutions for the smaller wheel. The water is conveyed to the 30-inch wheel by an open flume 5 feet wide by 7 feet deep, and to the 25-inch wheel by an iron tube 4 feet 6 inches in diameter. The turbines are of the horizontal type and drive by ropes a common countershaft. Each turbine is provided with a Snow governor acting directly on the turbine-gate. But though these have been found useful in checking the variation of speed due to small changes of load, they have not proved capable of controlling the speed of the wheels under large fluctuations of power.

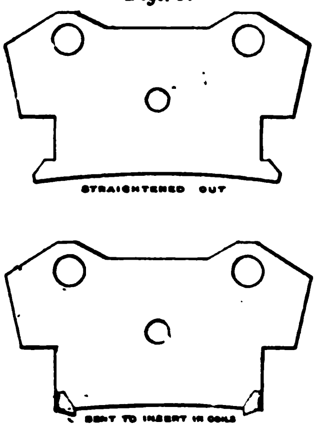
Arrangement of Generating-Plant.—The arrangement of the generating-plant is shown in Fig. 2, Plate 2. The alternators and exciters are driven from a countershaft 5½ inches in diameter on one side of the buildings, running at 300 revolutions per minute. On one end of this shaft are fixed the two pulleys driven

by the turbines, while the pulleys for driving the alternators and their corresponding exciters are placed along the shaft. The rope pulleys drive the shaft through claw-clutches worked by hand-levers, while the belt pulleys for driving the machines are driven through friction-clutches fixed to the shaft and worked by screw gear. The alternators and exciters can thus be stopped or started without shock while the turbines are running. Heavy double leather belts drive the alternators at 19 feet centres, and, owing to the tight side of the belts being on the top, a jockey-pulley is provided for each drive, placed under the belt, and as near to the machine pulleys as possible. The belts are 21 inches in width and the driving and driven pulleys are 44 inches and 33 inches in diameter respectively, the jockey-pulleys being 22 inches in diameter.

Generators.—The general design of the alternators is due to Mr. Gisbert Kapp, M. Inst. C.E., while the Author was responsible for the details of their construction. Two machines were supplied under the original scheme, but a third has since been added to meet extensions. Each generates two alternating currents having a phase-difference of 90°, and is capable of giving an output of 150 electrical HP. on a motor load at a difference of potential of 3,300 volts at the terminals. Two are capable of supplying the power required for the motors up to the present, the third being kept as a stand-by. The construction of the machines is illustrated in Figs. 3 and 4, Plate 1. The armature is stationary and the field-magnets rotate at 400 revolutions per minute. The stationary high-pressure coils are mounted on laminated iron sectors, which are laid close together in a strong cast-iron cylindrical shell made in halves to form the armature. This is 54 inches in internal diameter by 12 inches wide, and within it the field-magnet rotates. Each coil is wound on a former, and has sixty-three turns of double cotton-covered wire 0·12 inch by 0·09 inch in seven layers. The adjacent layers are carefully insulated by micanite cloth, while the complete coil was boiled in paraffin and was afterwards heavily covered with impregnated tape to a thickness of $\frac{1}{16}$-inch. In addition, during the process of mounting, a trough of fibre was interposed between the coil and the iron core. There are fourteen coils on the armature, the seven upper coils being for one phase and the seven lower coils for the other; each therefore contributes about 470 volts to the circuit. The coils are displaced to give the phase-difference of 90° by the interposition of idle laminated sectors. After the coils were wound, the charcoal-iron plates, *Figs. 5*, 0·013 inch thick, forming the laminated

sectors, were thrust through them, the corners being bent back for the purpose and straightened again as each plate was put in place. By placing the plates, each coated on one side with tissue-paper, one on the top of another, the laminated sector was built up, the coil when it was finished lying in the grooves formed on the side as shown in the *Figs.* There are two strong gun-metal end plates to each sector, and through these and the iron plates pass three insulated bolts, two of which are utilized to support the sector at the back end. These two bolts have projections beyond their heads which are screwed and fitted with brass coned nuts and ordinary nuts outside to lock them. The containing shell is drilled with tapered holes, and into these the coned nuts are tightened, the outer nut being locked upon the cone. If the support was obtained by means of projections fitting into parallel holes, either a good enough fit for working would render the rapid removal of a sector and coil difficult, or a fit loose enough for rapid removal would cause vibration in working. By adopting the method of support described, a perfectly tight fit is secured combined with the greatest ease of removal. The front supports for the sectors are two screws passing through lugs on the front gun-metal plates into the flange of the shell.

Figs. 5.



¼ full size.
CORE-PLATE.

The field-magnet is excited by a single coil, and consists of a steel wheel, from the rim of which project two series of poles, N on one side of the coil and S on the other. These poles are expanded on the face, and are curved over to form a circle of sixteen alternate N and S faces, which are presented to the armature core, with an air-gap of 0·33 inch between them and the armature core. Each pole-face is 12 inches long by 7 inches wide. The exciting coil, which consists of 1,612 turns of wire 0·120 inch in diameter, is wound on a cast-iron drum placed in the middle, between the projecting poles, this being positively driven by a couple of pins screwed into the steel casting. The magnetizing coil terminates in a pair of gun-metal rings lying side by side upon, and insulated from, a substantial cast-iron bush, which in turn is keyed upon the shaft. The exciters are ordinary two-

pole upright machines and need no description. The current is conveyed to brushes which bear upon the terminal rings referred to. There is a rheostat in the field-circuit of each machine.

The generator-coils are entirely surrounded by iron, a method of construction almost universal in machines for power transmission. By completely embedding the conductors, the insulating materials are relieved of strain; and for continuous work under trying conditions this is imperative, as mica, ebonite, fibre, and other such materials, are ill-fitted to transmit force. Again, it will be observed that the armature-sections with their coils are, in case of accident, easily removable; other things remaining the same, a machine which fulfils this condition possesses great advantages. The mill at Sheba runs day and night, Sundays included, and whatever happens, a stoppage of the crushing is the last thing which can be permitted. The machine shafts run in Babbitt-metal bearings, provided with two large sight-feed lubricators. The beds are mounted on heavy rails with tightening screws, so that the tension of the belts can be adjusted if necessary while the machines are at work.

Frequency.—The frequency at which the plant works is 53·3 per second, which is that given by generators with sixteen poles running at 400 revolutions per minute. The frequency is largely determined by local conditions, and there is no frequency which is best under all circumstances. A frequency of 50 per second is about the least which can be adopted consistently with obtaining satisfactory results for the lighting, which is usually a portion of the load, but when the lighting forms a small fraction of the work, rotary transformers or motor-generators can be used, so that, in determining the frequency, the lighting need not be taken into account. To show how circumstances may determine the frequency, a case may be cited where it was necessary that several 25-HP. motors should be coupled direct to shafts running at 320 revolutions per minute. The greatest number of poles that could be satisfactorily employed for motors of the power and speed required was eight; accordingly the frequency had to be 22 per second, and motor-generators were employed for the lighting.

Switching- and Regulating-Gear.—The switches and indicating instruments are mounted on polished-teak boards, all fittings being held off the wood by micanite washers and bushes. The insulation is very high, and wood was chosen because of the danger to fragile material arising from transport over rough country. The switch-board is divided into three panels, the middle and left panels being for the alternators, and the right one for the

exciters. The middle panel contains three high-pressure double-pole switches; double-pole fuses for one phase of the three alternators, and three ampere-meters to correspond; an ampere-meter to indicate the whole of the current in that phase; an electro-static voltmeter to indicate the difference of potential; and a second electrostatic voltmeter to measure the pressure at the mines. In addition there are mounted on the same panel three rheostats for the field-circuits of the alternators; the synchronizing gear, consisting of a pair of bars, the necessary plugs and switches, and two hot-wire voltmeters. On the left panel are three high-pressure double-pole switches and double-pole fuses for the other phase of the machines; three ampere-meters to correspond; an ampere-meter to indicate the whole of the current in that phase; and an electrostatic voltmeter to indicate the difference of potential. On the exciter-board to the right are switches and ampere-meters corresponding to the number of exciters, and a voltmeter common to all.

For throwing the alternators into parallel, a device introduced by Mr. Gisbert Kapp was employed, with the object of preventing large rushes of current between the machines if they are not quite in phase. The incoming alternator is plugged on to the synchronizing bars, and when approximate synchronism is obtained, as indicated by the hot-wire voltmeters, it is thrown into the main circuit, by closing, through a large choking-coil, a path between the synchronizing bars and the main omnibus-bars. The choking-coil effectually prevents a large rush of current, due to difference of phase, between the alternators, though at the same time allowing sufficient current to pass to pull the new machine into step. Synchronism being perfect, the choking-coil is short-circuited by a plug, and the main switch for the incoming machine is closed, which throws it direct on to the omnibus-bars, thus completing the operation. After the main switch is closed, the by-pass choking-coil switch is opened, and the plug is removed, the apparatus being then ready for throwing another machine into parallel should this be necessary.

Conductors.—These consist of concentric cables laid underground. The original scheme embraced two such cables, one for each phase, but a spare pair of cables has been laid since. The troubles experienced with the overhead wires used for lighting, due to the severe lightning storms in the Barberton district, induced the engineers to lay the cables underground, and they have since given no trouble. The Transvaal Government required, in terms of the Concession granted, that the cables should be laid 3 feet deep in

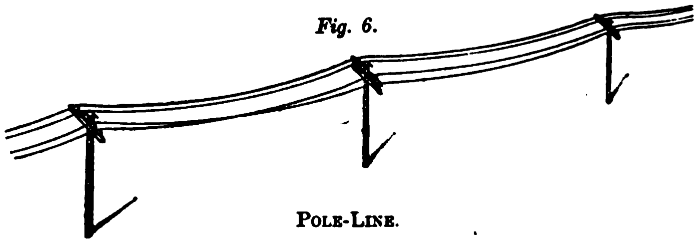
the ground, and cutting the trenches occupied eighty natives four months, much of the length having to be blasted through solid rock. The route follows for the most part the line of tramway belonging to the Sheba Company, which greatly facilitated the handling of the cable. The path of the cables is shown in Fig. 1, the length from the power-house to the mill being exactly 5 miles. It follows a circuitous route, and crosses Fever Creek five times. In four cases the cables lie in the bed of the stream, protected by masonry culverts; in the fifth case a wooden trough suspended above the stream from standards on each bank and forming a small suspension bridge, is employed.

The inner conductor consists of nineteen wires, 0·057 inch in diameter, and has a cross-section of $\frac{1}{20}$ square inch when stranded together. The outer conductor has also nineteen wires 0·057 inch in diameter, which are stranded on in two segments. The insulation between the inner and the outer conductor is composed of stranded hemp yarns impregnated with bituminous compound, and laid on to a thickness of 0·35 inch. Over the outer conductor similar yarns are stranded to a thickness of 0·23 inch, the cable being then covered with a lead sheath $\frac{1}{10}$ inch thick. On a bedding of jute over the lead two steel tapes are laid, and outside these a finishing layer of jute yarn is stranded on, and dressed with hard compound. The outside diameter of the cable is 2·3 inches; its resistance for the 5 miles of double conductor is 8·8 ohms; its insulation resistance exceeds 1,500 megohms per mile between the inner and outer conductors, and 800 megohms between the outer conductor and the lead. Its capacity is less than 0·5 microfarad per mile. Two pilot wires, first separately insulated, are stranded with the outer conductors, each wire lying midway between the two segments. Each length of cable was tested at the maker's works by an alternating difference of potential of 10,000 volts between the inner and outer conductors, 5,000 volts between the outer conductor and the lead sheath, and 5,000 volts between the pilot-wires and conductors.

The joints are made by copper connecting-pieces. The inner conductors are butted and coupled by a copper sleeve solidly soldered; the outer conductors are connected by a copper bridge-piece secured to them by clamps; the pilot-wires are twisted together and soldered, and are kept in position by ebonite distance-pieces. The joints are enclosed in a cast-iron box filled with an insulating compound poured in hot, and covered with an iron lid. These joints are watertight, and of high insulation; they are easy to make, and have never given trouble.

There is no fall of potential due to self-induction in these concentric cables, nor has the current in one pair of conductors any inductive effect on the neighbouring pair. But when overhead wires are employed, the conductors being of necessity some distance apart, there is not only a fall of potential due to self-induction in the lines, but, unless precautions are taken, the mutual induction of the circuits carrying currents of a quarter-phase displacement tends to produce inductive dissymmetry throughout the whole system. For carrying the four wires in the Burma mine installation which the Author has now in hand, there is a cross-arm fixed on each pole, and both wires belonging to the same phase are on the same side of the pole. The wires of one circuit run parallel all the way, but at half the distance between the power-house and the mine it is necessary to cross the other pair of wires, so that the effect of mutual induction in one-half of the line is neutralized by the effect on the other half. *Fig. 6* shows how

Fig. 6.



POLE-LINE.

the crossing is effected at the halfway pole, which is fitted for the purpose with an additional cross-arm.

Lightning guards are fitted at each end of the line to prevent accident to the machinery from the effect of induced charge. A guard is supplied at the power and motor end of the line for each concentric cable, consisting of a row of twenty-eight metal cylinders, 1 inch in diameter by 3 inches long, placed side by side parallel to and insulated from one another, each being separated from its neighbour by a gap of $\frac{1}{32}$ inch. These are placed between the two conductors of each phase which have a pressure of about 3,000 volts between them, the middle point of the series being efficiently connected to earth by a stranded conductor of nineteen No. 18 wires. The cylinders are made of an alloy of zinc and antimony, and an arc cannot be maintained between them, the dense oxide vapour produced by the discharge being non-conductive, and unable to carry the current. Provided with these guards, the installation has been worked through a heavy thunder-storm without damage, discharge sparks being, however, plainly visible

between the arrester cylinders during its continuance, accompanied by the crackling noise peculiar to such discharges.

The concentric cables terminate inside the transformer-house on tablets upon which are mounted movable double-pole fuses connected with the primary coils of the transformers. There are no switches, as the fuses, having insulated handles, can be easily removed to throw the transformers out of circuit if necessary. The secondary coils are connected with a distributing-board, from which, through suitable fuses, the currents are led through concentric cables to the motors.

Transformers.—When water is the source of power, a somewhat different course has to be followed in designing the transformers from that adopted when the latter form part of an equipment for town lighting. In the second case working at full load is the exception and at light load the rule. Accordingly the efficiency at light loads is all important, seeing that the cost of fuel, per unit generated, depends greatly upon the efficiency during the long hours of under-loading. Now apart from the fact that in power-plants working at full load is the rule, if there be plenty of water there is no reason to strive after high efficiency at light loads. The aim should be to obtain maximum efficiency for maximum load, or in other words, to get as much power as possible transmitted at full load for the water available, letting the efficiency at light loads, however, be quite a secondary consideration. Good regulating qualities, combined with high efficiency at full load and capability of running continuously at full load without overheating, are the chief requirements.

The transformers at Sheba are of the single-phase pattern, as distinguished from transformers of special design wound each for two phases. There is no advantage gained either in cost or in efficiency by employing the latter, so the plan of placing separate transformers on the separate phases was adopted. In installing special two-phase transformers there is disadvantage, as will be readily seen from the following consideration. If 200 kilowatts are required, four 50-kilowatt single-phase or two 100-kilowatt two-phase transformers may be provided. The cost of these would be about the same, as each of the latter is only a 50-kilowatt transformer duplicated, though effecting a small saving in iron. But taking the matter of spare plant into account the cost is somewhat modified. If a coil meets with accident, in the case of the single-phase transformers it means throwing out of circuit 50 kilowatts; consequently, only a 50-kilowatt transformer need be provided as spare; but in the case of the two-phase 100-kilowatt transformers

it would be necessary to provide as spare a transformer of 100 kilowatts, as the failure of a coil throws 100 kilowatts out of use. The point is that with two-phase transformers 50 per cent. capacity would have to be kept as spare, instead of 25 per cent. for the single phase. Four 50-kilowatt two-phase transformers with one spare could be used as an alternative, which would make the spares 25 per cent., but in either case the use of two-phase transformers increases the cost.

The working transformers are four in number, two for each phase, and a fifth is kept as spare. Each transformer has a ratio of 30 to 1 and is capable of giving an output of 50 kilowatts, its construction being shown in Figs. 7, Plate 2. The core is built of charcoal-iron plates carefully annealed, 0·013 inch thick, separated from one another by thin tissue paper. The plates are interleaved at the joints so as to make a complete magnetic circuit, the area being 350 square inches in the part of octagonal section inside the coils and 400 square inches in the rectangular part top and bottom. The vertical limbs are built up first and are bound together with impregnated tape; the bottom yoke is then put in and is secured to the vertical limbs by insulated through-bolts, when the core is ready for the reception of the coils. After these have been put in place the top yoke is inserted, and on its being secured also by through-bolts, the transformer is complete. The coils are wound on cylinders made of special insulating material, and there are three on each limb, two primary with one secondary between them. The object of dividing the primary in this way is to minimize the fall of potential due to magnetic leakage. It will be observed that the coils can be quickly removed, as on taking out the plates forming the top yoke, they have only to be lifted off. This is an advantage, as in case of accident repairs can be rapidly effected. In this particular design also, the coils, the temperature of which it is desirable to keep down, are most exposed, while between the core and the inside insulated cylinder there are provided vertical channels for cooling.

The transformers were originally placed in cast-iron cases and were immersed in resin oil, but this insulation failed. It was supposed that the oil would effectually protect the coils from moisture, as its specific gravity exceeded that of water, and at the same time it was expected to assist in dissipating the heat generated. But it appears that convection currents, induced in the oil due to heating, only serve to circulate in a state of fine subdivision any moisture or water which may be present—thus creating the very evil intended to be cured, and sooner or later

leading to a breakdown of the insulation. To what extent the failure was due to the oil alone the Author is unable to say. In the initial stages of working, owing to the bad governing of the turbines, the voltage often rose to a high figure, and a good deal of the trouble was doubtless thus caused. However, after the use of oil was discontinued and the transformers were taken out of their cases and freely exposed to the air, there was no further trouble. Later new primary coils were put on according to a method devised by the Author. This consists of winding the coils with insulated copper tape on edge, so that on each cylinder there is only one layer, and between any adjacent turns therefore only a very small difference of potential. The working of these modified transformers is most satisfactory. After a run continued for 30 hours at full load, the rise of temperature above the atmosphere measured on the core is 108° F.; while on the outside of the coils it is only 52° F. The maximum rise of temperature is attained in a run of this duration.

Motors.—The motors are of the rotary-field class and are wound for two-phase currents at a potential of 100 volts. Two of 50 HP. are installed for driving the mill, running at 640 revolutions per minute; two of 15 HP. for driving the crushers; one of 15 HP. for the Vanner room—these running at 800 revolutions per minute—and some small motors for driving pumps at different parts of the mine. These motors consist of a fixed part termed the "stator," in the winding of which flow the currents, transformed as to pressure, from the line, and a revolving part called the "rotor" in the self-contained windings of which local currents are induced by the rotating field. A section of one of the motors is given in Fig. 8, Plate 2. The stator consists of an annular ring built of charcoal-iron washers separated by paper and clamped together in a cast-iron cylinder which forms the body of the motor. This cylinder is provided with end covers which carry the bearings, and with feet to support the motor on its foundations. Around the inside circumference of the laminated iron ring there are holes through which the coils are wound, fibre tubes being first inserted in these to provide good insulation. The coils, wound so as to produce alternate radial poles inside the stator, are in two sets, one for each phase, and are interlaced so that the poles formed are resultant from the two separate currents passing. In effect, this produces inside the stator a magnetic field of alternate north and south poles, which rotates with a speed of revolution depending on the frequency and on the number of poles. The rotor consists of a number of charcoal-iron disks

mounted on the shaft, clamped together and separated from one another by paper. These are pierced with circular holes near their edges, and the winding consists of a number of solid copper rods threaded through these holes and at each end, connected all together by copper rings to which their ends are soldered. The rods are insulated from the disks by first inserting fibre tubes through the holes.

It will be seen that the lines of force pass from the stator into the rotor, the latter serving to complete the magnetic circuit; and that as a consequence the field is formed of a number of closed magnetic circuits moving circumferentially with a certain velocity. As the field rotates, the copper rods of the rotor are cut by lines of force and currents are induced in them which, tending to stop the rotation of the field, compel the rotor to follow its movement. There results a motor working purely by induction, without any electrical connection between the fixed and the revolving parts.

There must be relative movement between the rotating field and the rotor, or the currents could not be generated in the rods of the latter, and the speed of the rotor is therefore not quite so great as that of the rotating field. The difference between the two speeds is called the "slip," and the currents in the rotor depend upon this; as the movement, so far as inducing electromotive force in the rods is concerned, is electrically the equivalent of the rotor, with the field at rest, running backwards at a speed equal to the slip. In running, the slip adjusts itself to requirements and is always just enough to allow of such currents being generated in the rotor bars as will give the necessary torque for the particular load on the motor. If the motor is running light, the speed of the rotor nearly coincides with the speed of the rotating field; as, having only friction to overcome, the currents in the rotor bars necessary to provide the required torque are extremely feeble. When running fully loaded, the slip is about 3 per cent. for the 50-HP. motors and $3\frac{1}{2}$ per cent. for the 15-HP. motors; so that, the difference of potential of the supply being constant, the variation of speed from no-load to full-load is represented by the above fraction.

The foregoing description of rotor applies to small motors. The rods being all joined together at each end, such a rotor has an extremely small resistance; and at the moment of starting, the slip, or relative movement of field and rotor, is equivalent to the speed of the field, the rotor being momentarily at rest. As a consequence, compar[illegible] currents are induced in the

rods, causing a correspondingly large current to be drawn from the line; and though for motors up to about 10 HP. the excess of current in starting is in no way objectionable, in large motors it is necessary to adopt devices to prevent this excess and its consequent evil effects on the even working of the plant. In the case of the small motors employed for pumping, the short-circuited rotor described was used, but the 15-HP. and 50-HP. motors had the windings of their rotors grouped in such a manner as to allow of a resistance being inserted in the circuit at starting. For this purpose, the conductors are arranged in three groups and are attached star-wise to a common junction, with their free ends brought out to three insulated rings on the shaft. This is supplemented by a set of three resistance coils also connected star-wise, with their free ends connected with brushes resting on the insulated rings. The coils are provided with a regulating switch

Fig. 9.

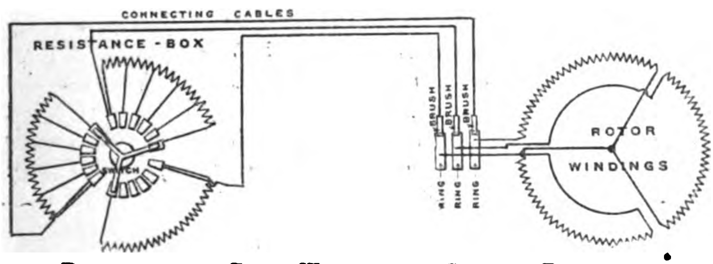


Diagram of the Rotor Windings and Starting Resistance.

working all three branches simultaneously; thus the resistance inserted in the rotor circuit can be gradually taken out as the speed of the motor increases. Apart from the resistance preventing an excess of current, its insertion has also the effect of increasing the torque at starting, as excessive currents flowing in the rotor conductors diminish the resultant field. The arrangement indicated is shown in *Fig. 9*, and by using a resistance in this way the motor can start against full running torque without drawing more than the normal current from the line. If twice the normal current is allowed to pass, twice the normal torque is obtained.

The behaviour of the induction motor under load can now be understood. As additions are made to the load, the slip becomes greater, and the currents in the rotor conductors are consequently increased until they are of sufficient magnitude to provide the necessary torque for the increased load. This continues until a certain load is reached, but after a time, owing

to the currents in the rotor weakening the resultant field, the increased current produces actually a diminished torque, and the result is that the motor can no longer respond to the increase of load, but comes to rest. A good margin of power is essential, and in the 50-HP. motors referred to, for driving the mill, this state of things was not reached until the power approached 65 HP.

If the pressure at the motors is allowed to fall, larger currents are required in the rotor conductors to develop the power. These currents re-acting on a weaker field reduce the margin of power, and it is therefore of importance that the regulation be good and that the difference of potential at the motors be kept as constant as possible. If the pressure is permanently raised, the frequency remaining the same, the power is increased as the square of the pressure. This is because the field is strengthened in proportion to the pressure, and in consequence the currents in the rotor conductors may be similarly increased, the torque being proportional to the product of the rotor currents and the resultant field. The percentage of margin will be for the increased pressure, as before, so that not only is the power increased but the margin of power is increased in the same ratio. The pressure at which it is permissible to work a motor depends upon the rise of temperature which can be allowed without interfering with safe running. The 50-HP. motors at Sheba attain a temperature of 170° F. in an atmosphere of 87° F., making the rise 83° F., which is not in any sense objectionable. If the field remains the same, the motor will, within limits, give increased power in proportion to the speed or frequency. To keep the field constant, the potential must be increased in proportion to the frequency, but, as in this case, a larger current in the rotor windings is not permissible; the torque can only be the same as with the lower speed, the advantage in power being therefore merely that due to faster running.

Naturally, the no-load current must be comparatively large, as this has to magnetize the motor, and, due to the existence of an air-gap in the circuit, the magnetic resistance is considerable. This does not mean that the motor is inefficient, however, for the current lags behind the impressed difference of potential, and the true energy is, in consequence, but a fraction of the apparent energy given by the product of difference of potential and current. In the case of the 50-HP. motors, for example, the no-load current is 70 amperes per phase at 100 volts, which gives 14,000 apparent watts, whereas the true watts are only 1,400. The current taken by these motors per phase at full load is 250 amperes, so that, it

will be observed, the current passing at light load is 28 per cent. of the current at full load. But, while the ratio of the real to the apparent energy is only 0·1 at no load, at full load it rises to about 0·8. The full-load efficiency of the motors is about 92 per cent. for the 50-HP. motor, to which these figures refer, while the efficiency of the 15-HP. motor is 90 per cent.

Nature of the Load.—The mill load is *per se* an ideal one, being constant and not subject to variation from moment to moment. The mechanism is of the simplest character, consisting merely of revolving shafts fitted with cams to raise the stamps at regular intervals. There are sixty stamps, and the cams are so arranged that the turning moment is uniform, since the same number of stamps is being lifted at every instant. Each head originally weighed 791 lbs., and was raised 7 inches ninety-four times per minute. It was reckoned that 90 HP. would be required for driving, a margin of 10 HP. being allowed for the shafting. Since the installation was put down, however, the weight of the stamps has been increased to 850 lbs. each; but the two 50-HP. motors are still found capable of driving now that everything is running smoothly and the shafting is all bedding well in its bearings.

The mill load differs from the crusher load, which is extremely unsteady. It was originally estimated that 15 HP. would be sufficient for two crushers with jaws 15 inches by 24 inches; but experience has shown that at least a 15-HP. motor is required for each crusher, to be on the safe side. This is due to the fact that with an irregular load a large margin is necessary. Again, the power required increases in proportion to the time the crusher works consequent on its heating. As the Sheba Mill runs continuously four crushers are used, one pair working while the other pair is cooling. One 15-HP. motor is belted to each crusher, and even with a margin such as this provides, the carelessness of the natives in admitting heavy pieces of rock occasionally leads to the fuses melting.

Recently ten new "Rand-Slugger" rock-drills have been sent out for the purposes of development. These have cylinders 3⅛ inches in diameter, and when running hard require each 88 cubic feet of free air per minute compressed to 75 lbs. per square inch above the atmospheric pressure. This would require about 10 HP. applied to the compressor for each drill. It was originally intended to drive the 100-HP. compressor by electricity, but it was unfortunately found that the quantity of water could not always be relied upon, and since either the new sixty-stamp mill

in course of erection or the compressor would have to be driven by steam, it was decided to employ electrical driving for the mill only. The compressor referred to, having only one cylinder, does not constitute a desirable load for an electric motor. Compressors which are to be electrically driven should have at least two cylinders, with their cranks at right angles, but three cylinders are much to be preferred. Single crank compressors are quite unsuitable.

All the pumps in the mine are of the three-throw single-acting type, and give an approximately uniform moment of resistance. These are the most suitable force-pumps for electric driving and work satisfactorily; but for moving a large volume of water through a comparatively small lift the centrifugal pump has no equal. In the Burma Mine Installation already referred to, 12-inch centrifugal pumps are to be used, coupled directly to two-phase motors, lifting 40 feet and running at 800 revolutions per minute. The advantage of dispensing with all gearing here is apparent, and the moment of resistance is absolutely uniform.

Working.—It was estimated that 500 HP. would be yielded by the water, but experience soon showed that this estimate was too favourable for certain seasons of the year. It is doubtful whether the water can be relied upon to supply at the mine, continuously, more than 250 HP., but this will provide for 120 stamps, with the pumping and lighting. Oil insulation for the transformers having been abandoned at the start, the running has been a record of smooth working. The following Table gives the gross running time for the 12 months ending September, 1897, and it will be

Month.	Pressure "on."			Pressure "off."			Days.
	Days.	Hrs.	Mins.	Days.	Hrs.	Mins.	
1896.							
October . .	30	18	10	0	5	50	31
November . .	29	18	40	0	5	20	30
December . .	30	18	10	0	5	50	31
1897.							
January . .	30	21	27	0	2	33	31
February . .	27	21	22	0	2	38	28
March . . .	30	15	32	0	8	28	31
April . . .	29	20	10	0	3	50	30
May . . .	29	19	40	1	4	20	31
June . . .	29	17	25	0	6	35	30
July . . .	30	20	17	0	3	43	31
August . .	30	8	55	0	15	5	31
September . .	29	7	50	0	16	10	30
	360	15	38	4	8	22	365

observed that out of a possible 365 days, the pressure was off the conductors for less than 4½ days. During this period 46,000 tons of ore were milled.

The mill runs day and night, and these results were obtained at a time when there was no spare plant installed; both turbines, two generators, and the whole of the gearing, ropes, belts and shafting having to run continuously. It is not unusual after the clean-up at the beginning of a month, to run to the end of the month without stopping. The time of stoppage is occupied chiefly in inspecting the water-race, overhauling belts, ropes, &c., and in executing general repairs to the machinery.

The turbine governors are not wholly relied upon to control the speed. The crushers are very trying to any governor, and the arrangement of driving one countershaft by two turbines of different size is capable of considerable improvement. On account of the slow governing it was found necessary to institute a code of bell signals, and these are worked through the telephone wire, between the power-house and the mill, relays in the telephone instruments being used to strike 6-inch gongs.

The staff at the power-house consists of eight Europeans and twelve natives, and three shifts are worked per day. Every half hour simultaneous observations are taken on each instrument in use, and these are recorded in a log-book. Remarks upon the running are also made and signed by the chief chargeman. This stimulates a healthy rivalry between the shifts.

When running a quartz mill for the production of gold, there is no time to conduct tests or to make experiments; the object of the management being to keep the mill working. Accordingly, there have been no carefully-conducted tests of efficiency, but the following results are sufficiently near the truth to indicate what may be expected from such plant.

At the time the observations were made, the 30-inch Victor turbine only was driving with 30 feet head of water. According to the makers' lists, the wheel with this fall gives 200 brake HP.:—

		HP.
Power of turbine		200
Power required for the mill	100 HP.	
„ „ „ vanner	10 „	
„ „ „ crusher	15 „	
„ „ „ pumping and lighting	15 „	
		140
Total loss		60

Efficiency 70 per cent.

It may be assumed that 5 per cent. of the power of the turbine was absorbed by the ropes, belts and countershafting, so that only 95 per cent., or 190 brake HP., reached the alternators.

The Author is convinced that for driving mining machinery, alternating currents of two phases possess in many respects great advantages over continuous currents, and this is quite irrespective of whether the power is transmitted at high pressure from a distance or is distributed at a comparatively low pressure from a local generator. Though the induction motor is much superior to the continuous-current motor as an electrical machine, engineers in England are only beginning, and with some diffidence, to take it up, but a few years will no doubt see a great change in this respect.

In conclusion the Author desires to acknowledge his indebtedness to the Chairman of the Sheba Gold Mining Company, to the Company's Chief Engineer, Mr. John Rance, and to the contractors, Messrs. Johnson and Phillips, for the aid they have given him in the preparation of the Paper.

The Paper is accompanied by eight tracings, from which Plate 2 and the Figures in the text have been prepared.

[Discussion.

Discussion.

Mr. W. H. Preece, C.B., President, said it was his pleasant duty to propose that a vote of thanks be awarded to the Author for the very practical Paper that he had submitted. The Institution was always gratified, in these days of severe foreign competition, to hear that an English firm had fitted a mine in a distant country with apparatus designed in England, and the members were much indebted to the Author for having given so fully and completely all the details of the measurements, of the power exerted, the efficiency, and the other conditions realized by the machinery. He called the members' particular attention to the fact that in all the Papers on electric machinery and electrical appliances brought before the Institution, the one striking element was the fact that means and instruments were applied to measure, with the greatest possible accuracy, every factor in that machine. There was nothing that tended so much to improve machinery of any kind as a system of measurement of that character. Mr. Preece.

Mr. Esson, having exhibited on the screen a series of photographs of machines described in the Paper, referred to the method of driving from two turbines on one countershaft. It left much to be desired, and had only been adopted because the engineers of the Sheba Mining Company insisted on using some old plant that was on the ground. If the two turbines had been of the same size the disadvantage would not have been so great, but with turbines of two sizes, working on a common countershaft, there was a great difficulty in proportionally distributing the load between them. Accordingly a loss of about 5 per cent. was incurred in driving the countershafting. Instead of a return of 70 per cent. at the mine, 75 per cent. might have been realized if a method had been adopted whereby all the countershafting and driving-gear could have been dispensed with. In the Burma ruby mine installation there was a low fall as at Sheba, but each alternator was directly driven by ropes from a single Pelton wheel, and consequently nothing intervened between the wheel and the alternator but one set of ropes; there was no countershafting to drive. All the wheels were controlled by one governor, and that was essential. The only proper way of governing a number of Pelton wheels, driving alternators which had to work Mr. Esson.

Mr. Esson. in parallel, was to control all by one governor. In another transmission installation in the Straits Settlements, upon which Messrs. Johnson and Phillips were engaged, 300 HP. had to be conveyed to a mine 7½ miles distant. There was a high fall, and the Pelton wheels were running at a speed of about 400 revolutions per minute, so it was possible to couple the alternators direct on to the Pelton-wheel shafts. That was by far the best method of working, and it had been also arranged that one governor governed the three wheels. The type of generator shown in Figs. 3, Plate 2, had been recently modified by interlacing the coils as in the motors, because it was found that then a much smaller fall of potential between light load and full load was obtained than when the coils were wound singly. The machine shown in Figs. 3, Plate 2, consisted practically of two single-phase alternators, the top half of the armature constituting one machine, and the bottom half the other; but with the interlaced coils a much better result was obtained than with the type of machine shown. Again, the field-magnet described in the Paper had been changed. It was a very good one for machines which ran on a non-inductive load, that was, on a load of lamps, but on an inductive load there was too much magnetic leakage, so it had been abandoned, and now a field-magnet of radial poles, each having a separate coil wound on it, was used. A much smaller fall of potential was thus secured than with the type of field-magnet used at Sheba. With regard to the relative outputs of two-phase and single-phase machines, if a non-inductive load was put on a two-phase machine, undoubtedly its output was higher, quite one-half more, than with the single-phase machine; but generally, the two-phase machine had to work on an inductive load, and there was not the advantage which would be obtained from working on the non-inductive load. First, for a given output, the impressed electromotive force had to be about 25 per cent. greater than the terminal electromotive force when working on an inductive load. Again, a current 25 per cent. in excess of that which would accord with the watt output of the machine had to be generated. There was thus obtained from the two-phase machine, working on an inductive motor load, just about the same output as was obtained from a single-phase machine of the same size, working on a non-inductive load. He had not, in the Paper, touched upon the application of the induction-motor to coal-mining; but in this industry it had a distinctly important bearing, as in gold-mining and gem-mining. One of the great advantages of the induction-motor was that it

had no commutator, and there was practically nothing to go wrong about it. He was surprised to find that in fiery coal-mines, where there was liability of explosion, the direct-current motor should still be employed. It was necessary with it to take the greatest precaution to prevent an explosion by enclosing the commutator in a gas-tight casing. The induction-motor was ready to hand, it had no commutator, and it did not matter how it was treated. The short-circuited armature or rotating part of the induction-motor might be steeped in water, and it would suffer little damage. One of the most interesting points about power-transmission plants was the way in which the line was guarded from the effects of lightning. A lightning guard had been devised by Messrs. Siemens and Halske,[1] which consisted of two curved copper forks mounted on two insulators, one being connected to earth, and the other to the line. If lightning struck the arrester an arc was formed in the small space at the bottom between the two forks, and the current of air made it rise quickly to the top of the forks, where it could not be maintained. It thus acted quite automatically. That arrester had done very good service in the Randt, and it was now being adopted in an installation Messrs. Johnson and Phillips were erecting in the East. Replacement arresters were not adapted for transmission of power work and were always giving trouble. Here the arrester was always ready to act. At the Sheba mine, Wurtz arresters were employed; they were made in America and consisted of composite metal cylinders, fulfilling the same conditions, and the apparatus required no replacement. Mr. Esson.

Prof. W. E. Ayrton thought that one of the most interesting features of the Paper was that it showed that English engineers were at last becoming alive to the importance of the vast field that lay open to them of the transmission of power by polyphase electric currents. He had been very much struck, while travelling through America in 1897, with the use that was there made of the electrical transmission of power, particularly in connection with mining; over as great distances as 100 miles, and at 30,000 volts, or even, as he had heard in one case, of some 35,000 volts for 100 miles. The advantages possessed by the polyphase motor were rightly emphasized by the Author. The only regret was that this should be necessary in England at the latter end of 1898. These advantages had been realized and utilized for the last seven or eight years on the Continent of Europe and in the whole of Prof. Ayrton.

[1] Electrotechnische Zeitschrift, vol. xviii. p. 214.

Prof. Ayrton. America. Since engineers were shown in 1891 the transmission at Frankfort of more than 100 HP. over more than 100 miles at an efficiency, very carefully measured, of about 75 per cent. by means of polyphase currents, engineers in England ought to have grasped, as Europe generally and America had grasped, the importance of that method of solving such problems. The Paper also brought out the fact that while a few years ago the education of a mining engineer would have been regarded as satisfactory if it embraced merely mechanical engineering principles and practices, it was now quite clear that if a mining engineer was to extract the ore and deal with it economically, he must know a good deal of electrical technology in order to be able to utilize the neighbouring water-power by bringing it to the mine and so saving the consumption of coal. The generating station at Sheba seemed to possess a considerable number of faults, the mass of counter-shafting, the use of rope-driving for the turbines, the use of belts for the other parts, the jockey pulleys, and so on; but the Author had said he would not have used the method had he not been compelled. With regard to the dynamo, he would hardly like to criticize a machine which was designed by so eminent an engineer as Mr. Gisbert Kapp, but at the same time it seemed susceptible of improvement. Much of the circumferential space in the dynamo appeared to be wasted by the distance-pieces which had been inserted to produce the difference in phase, Figs. 3, Plate 2. There was not merely on the left-hand side an idle space, but there was a very large idle space on the right-hand side, which meant a considerably diminished output for the size and for the weight. Why, also, should those air-gaps be made, between the sector plates, about as large as the air-gaps between them and the pole-pieces? The air-gaps had distinct disadvantages, as they were included in the magnetic circuit. One air-gap was necessary in the magnetic circuit of a rotatory machine, but why have more? In addition to increasing the reluctance of the circuit, it also apparently caused the coils to be much less embedded in the iron than would otherwise be the case, and therefore induced a certain drag on the coils which the Author rightly pointed out would not exist if the coils were entirely buried. He had not made any experiments or seen the particular dynamo, but he should predict, from the shape of the pole-pieces and the shape of the coils, that it would give a peaked form of wave, which was a bad shape of wave, since for a considerable period there was a low electromotive force arising from the particular shape of the ends of the moving pole-

pieces which led to the number of lines of force produced by a pole and embraced by a coil not altering for some time, and, therefore, producing no electromotive force. Perhaps, also, the Author would explain why the corners of the sector plates were cut off; this tended, apparently, to increase the gap. It would at any rate have seemed preferable to bring them up and not cut them away, the object being to get as nearly closed a magnetic circuit as possible in that direction. There seemed to be a special object on the part of the designer in making an extra reluctance in the magnetic circuit. He supposed the Author's expression "boiled in paraffin" was only figurative; paraffin wax should not be boiled, for its insulating property was thus seriously diminished. It should not be heated above a temperature of 110° C.; and even when only heated to that temperature, as in the manufacture of condensers to drive off the water-vapour, the whole of the paraffin wax was sold daily for candles and was not used the next day, because even heating to 110° C. was sufficient to seriously diminish the insulating quality of paraffin wax. Were it raised to the temperature of boiling wax, it would be almost ruined from an insulating point of view. He was much interested in the suggestion of synchronizing alternators by means of two hot-wire volt-meters, and he would be glad if the Author could describe the exact method he employed. The wires that he used on the exciting coil in the generator were round, whereas flat wires were used in winding the stationary coils. That, again, perhaps, was for some good reason, but why round wires in the stationary coil? With regard to the conductors which connected the generating station with the motor station, he noticed that four conductors were employed in two separate cables. Was that preferable to using three conductors only in one cable? With the two-phase system three conductors could be employed by making one of twice the cross section, the current being about 1·4 times that in the two others. He did not understand why lightning conductors were required when the cables were laid 3 feet under the ground. He thought in that position they would be sufficiently protected. Prof. Ayrton.

Mr. W. H. Preece, C.B., President, said they were just as liable to disturbance when 3 feet underground as when placed on poles. Mr. Preece.

Prof. Ayrton supposed that the Author's expression "There is no fall of potential due to self-induction in these concentric cables," was used figuratively, for there was certainly a small fall of potential. As to the use of oil in the transformers, the impression was Prof. Ayrton.

Prof. Ayrton. conveyed that oil had proved a failure. He thought that the breakdowns in the insulation might not be attributable so much to the oil as to the method in which the transformers were originally wound, and that the improvement noticed at about the time he dispensed with the oil was due to the introduction of the very much better system of winding to which he referred in the Paper. The method used originally was to wind the wire in continuous layers along the whole length of the core; there was thus great difference of potential between the ends of successive layers. That method had been abandoned 30 or 40 years ago in connection with the winding of the induction-coil. It was realized that the layers must be divided by ebonite disks which divided the coil into several short sections. The wires had thus to be wound in little pockets, and the difference of potential between the ends of successive layers was correspondingly reduced. It might be only a coincidence that when the Author took the coils out of the oil he found that the breaking down was discontinued, seeing that very shortly afterwards he introduced the system which he had described—certainly a very much better one—of winding with edged flat copper, for in that case no two convolutions differing much in potential would ever be brought near together. There was one reason why the introduction of resistance coils was so important in starting an induction motor which had not been perhaps generally realized. The resistance prevented large currents being induced in the stationary portion which would be injurious and would weaken the field; but another reason for introducing resistance was that it diminished the time-constant of the circuit, that was, the currents in the stationary and rotatory parts of the motor were brought more into phase with one another. The same effect was produced as in a steam-engine if the greatest admission of steam was combined with the most efficient position of the piston. The lag that occurred in ordinary alternating current working was analogous with having a considerable pressure of the steam when the piston was in a bad position near a dead point, and clearly if that could be removed and the greatest amount of steam or the greatest pressure in such case could be brought about when the piston was at its best position, a better arrangement would result. The introduction of resistance—he did not know that he had ever seen that pointed out before—in starting an induction-motor had the effect of diminishing the time-constant and bringing the currents more into phase, so that the large currents in the stationary portion and the large currents in the moving portion were nearer together and

Prof. Ayrton.

could act better in producing a large starting torque. The Paper appeared to be one of considerable interest, and the results achieved had a practical and important economical bearing, as would be obvious to every Englishman, seeing that the Author said, at the beginning of his Paper, that the installation described had saved the Sheba Company £10,000 per annum.

Prof. Forbes.

Professor G. Forbes regarded the Paper as one of very great importance, as drawing attention to one of the principal applications of electrical transmission of power. In the last few years the fact had been more and more impressed upon his mind that the greatest application of electrical transmission of water-power which would be seen in the next few years would undoubtedly be for the purposes of gold-mining. The reason was obvious: first, many gold mines were capable of giving a large output, but had no means of getting fuel in their neighbourhood, and, consequently, the working expenses were too high. He could mention many gold mines which had come under his personal observation which were absolutely unproductive, and could not be worked for that reason. In consequence a very large price could be obtained at those gold mines for the power that was transmitted, and it therefore became possible to invest a large capital in copper to transmit power to very great distances when the return was so great. The second reason was that the demand for the power was continuous, day and night, all the year round; and, in such a case, the superiority of water-power became enormous over that of steam-power. The Author had cited some of the advantages of using electrical power for gold-mining, and to many engineers, who had not followed the progress of electrical practice of late years closely, it might appear somewhat startling that the induction motor was of all machines the least complicated, and, on account of its simplicity of construction, least likely to suffer serious injury or damage through rough usage. Of that there was not the slightest doubt. The induction motor was peculiarly suited to the rough usage it was likely to experience in a gold-mining district. It was to all other electric motors somewhat in the same relation as a "Pelton" wheel was to a turbine for its simplicity and absence of liability to get out of order. Compared with other machinery—steam-engines or machinery of that class—it was incomparably simpler and less likely to get out of order. In the Randt it might be taken that about 2 tons or 3 tons of ore per day were crushed per HP. The mean between those two

Prof. Forbes. amounts gave a cost of about 2*s.* per ton of ore crushed, which was a remarkably low figure. At Coolgardie a year or two ago the proprietors were willing to support any scheme where they would be obliged to pay 10*s.* per ton. That showed that transmission to a long distance—where the expenses were increased by the conductors—was likely to be successful, and to become remunerative. He had not much preference between 2-phase and 3-phase systems—either would work the induction motor satisfactorily—but he would support the view the Author had expressed—that the 2-phase was the preferable. The case mentioned by the Author could not be considered a long-distance transmission in any way, as it was only about 5 miles, and it went a circuitous route, owing to the fact of underground cables being used. If it had been overhead cables it would have been much closer; consequently, the pressure was only 3,300 volts, which was very moderate and did not give an indication of what would happen with long-distance transmission. He would ask whether the dynamo machine was not practically identical with that designed by Mr. C. E. L. Brown for the Lauffen and Frankfort Exhibition in 1891. It consisted of two flat disks or wheels, facing each other, with an iron cylinder joining them, as it were, and the peripheries had the poles projecting inwards and alternating one with the other. He had understood that that type of dynamo had been abandoned because the magnetic leakage between the poles was found so great that it was not efficient. He understood that at Oerlikon their manufacture had ceased, and he should have thought that it was not so satisfactory a design as some which had been introduced later. It appeared from the Paper that the transformers were originally placed in cast-iron cases and were immersed in resin-oil, but that insulation failed; the oil was put in to keep out the water; but convection currents induced in the oil, due to heating, only served to circulate in a state of fine subdivision any moisture or water which might be present, thus creating the very evil intended to be cured, and, sooner or later, leading to a break-down of the insulation. In considering the tenders that were made for the very large transformers at the Niagara Works two classes had been put before him. One contemplated the use of oil like the circulating one shown by the Author, and the other was provided with an air-blast, the object in both cases being not to produce a high insulation, but because in transformers of a very large size the heating became very great. A very economical transformer was obtained, but artificial cooling had to be introduced. His own opinion was

that the oil had not had a sufficient trial, and he preferred Prof. Forbes. in the first place to trust the air-blast, and it had proved perfectly successful. Later on the oil had been introduced, and the experience with oil-insulation had been very satisfactory. He thought that the circulation of the oil which had been introduced in the last transformers at Niagara would not be the less likely to carry moisture with it than the stationary oil which he presumed was employed at Sheba. With regard to the conductors, he was surprised that in the Author's case it was found necessary to use underground cables. Electric transmission to a long distance would certainly not be possible in the immediate future by the employment of underground cables, because the cost of an underground cable was between four times and ten times the cost of a bare copper wire, and the cost of the copper in a long transmission line was a serious item of expense. Therefore it would be increasing the capital expenditure perhaps five or ten times. The Author said that the troubles experienced with the overhead wires used for lighting, due to the severe lightning storms in the Barberton district, induced the engineers to lay the cables underground, and they had since given no trouble. Professor Forbes could well believe they had not given any trouble, but he should be surprised if that practice would be followed by others. He had never seen such a place for lightning as the Transvaal. Thunder-storms were very severe indeed, and it was well known that Mr. Rhodes' telegraph line through Rhodesia was subject to continual interruption. There was seldom a day that some part of it had not to stop working. Also there had been great trouble with the electric-light works in Barberton and other places. Probably the Author was aware that, in the neighbourhood of the Sheba mines, there were other places which were using electrical transmission of power for their gold stamps, and they had at first been troubled with lightning. He had received reports from mines where a different mode of procedure to that adopted at Sheba had been followed. Instead of incurring the enormous expense of buying insulated cables and burying them, also at great expense, 3 feet below the ground, and most of it through rock, a bare overhead copper conductor was still used; but there were joined with that conductor all the wisest precautions which could be thought of, evolved from past experience, which would be likely to prevent trouble. Among other things the Siemens and Halske lightning arrester had been employed. The line was working at 10,000 volts to 11,000 volts, and other precautions besides the simple use of that

Prof. Forbes. arrester were taken. The special manner in which the arrester was placed, undoubtedly had some influence on the result; but the result was simply that there was no trouble whatever now. Ever since the change had been made—since the line had been protected in that way—he had felt, with perfect certainty, that there was no need for trouble in future about lightning in any part of the world, and that transmission lines could be made absolutely proof against this disturbance. Barbed wire was used at Niagara, but in the case he was speaking of barbed wire was not used. He would wish to have inserted it in a case like that which he had mentioned, as it was most desirable, but in that particular case wire was used for making an earth, because there was a difficulty to get earth at a good many points where it was wanted, and a wire was used, but it was not barbed wire. At the mine of which he had been speaking, which had not been established so long as the Sheba mine, but where 10,000 volts and 11,000 volts were used with a bare overhead wire, the generators had been lately running for 88 days continuously, 24 hours a day, 7 days a week. During that time—88 days—load had been lost about 30 minutes in all through line fuses melting. He should imagine it to be one of the worst places for lightning in the world, and any arrangement that would stand the lightning of the Transvaal would stand the lightning of any place he knew of.

Mr. Ravenshaw. Mr. W. H. Ravenshaw noticed that the Author had stated his surprise that multi-phase work had not been more used by English engineers. For some years after the Frankfort Exhibition it was always understood that patents were held in a foreign country controlling the manufacture of multi-phase machines, but during the last 3 years or 4 years that matter had been cleared away, and several English firms had been taking up the subject. Many firms had not taken it up, however, because they had all been so extremely busy with continuous-current work. In the application to mining he thought that multi-phase working had many advantages, especially in fiery mines. He believed that, in South Wales, there was little electrical working in the fiery mines, simply owing to the fear of the sparking of the motors. The continuous-current enclosed motor was very difficult to build in any large size, and still more difficult to obtain. He thought the Author's machines would hardly have been suitable for that class of work. Mr. Esson said that his 50-HP. motors were pulled up with 65 HP. In winding, or, hauling up a steep incline, there was a great danger if the motor pulled up. It must go on; in fact, in many cases no fuses were used, and magnetic cut-outs were tied down.

If a train weighing 20 tons or 30 tons was coming up an incline of perhaps 1 in 10, the power must not fail, and if the motors were at all likely to give out, it would be extremely dangerous. The Author had also mentioned that he had improved on the dynamos greatly. He would expect to find that they would have a very heavy drop, and that was very bad for an induction motor. Consequently, he was not at all certain that it was not a good thing engineers had to wait a year or two. Mr. Ravenshaw.

Mr. A. C. Campbell Swinton had had considerable experience with transformers in which oil had proved exceedingly satisfactory. They were small, ranging up to 30 kilowatts, but there were about thirty, and the total power was considerably more than that which the Author referred to. They were in use at Scarborough and were mostly in pits under the foot pavements; some had been in use for 5 years. There had been three cases of a transformer failing, but in no single case could it be attributed to the oil. He thought, as Professor Forbes had said, the use of the oil was not merely for the purpose of keeping water out and keeping the insulation dry, but that it also had the effect of preventing local heating, which really determined the safe load at which a transformer could be worked, in the same way that the weakest link determined the strength of a chain. About 3 years ago he had occasion to examine the question of two transmission plants, one for a coal mine for the Armiston Coal Co., in Scotland, and the other for dock-pumping at Smith's dock on the Tyne, and in both cases he studied most carefully the question of the relative merits of multi-phase and continuous currents. In neither case was the distance very great. In the case of the coal-pit the maximum distance was 1,500 yards, and in the case of the dock, which was a floating one, where 500 HP. had to be transmitted, it was only about 200 yards. There were other points to be considered, but the cost entirely turned the balance against the multi-phase system in each case. After the estimates were reduced to a common denomination, the multi-phase motors, generators and cables, came to something like 20 per cent. more in first cost than did continuous-current plant. He did not know why that should be, and he thought they ought really to be cheaper. He supposed it was because, at that time at any rate, manufacturers were largely engaged in making continuous-current machinery in England, and could not produce multi-phase machines so cheaply as continuous-current machines. At any rate, they did not wish to take the risk without charg- Mr. Swinton.

Mr. Swinton. ing a very large price. The advantages of the multi-phase motors were quite undoubted in certain instances, but when the large difference in cost was considered, the advantages did not warrant the extra cost in the particular cases quoted, because although commutators might be troublesome to some extent, still, if machines were properly made, they really did not, after all, require very much attention. He might mention that in the pit in question about 500 HP. was transmitted. It was not a fiery mine, and therefore it was simply a question of first cost on the one hand and upkeep of commutators on the other. In the case of the dock there was the further point that a variable speed was required for the motors, which rendered multi-phase currents unsuitable.

Mr. Ristori. Mr. E. J. Ristori had lately seen at work some turbines and dynamos of about 800 HP., working both continuous and alternating currents, and running at only 50 revolutions per minute; and he thought it should not be difficult to arrange machinery so as to have any speed suitable for any special water-power. He thought that a considerable amount of water-power was going to waste, which might be very usefully employed in mines or in other works. He recollected in 1892 or 1893, when he was seeking for water-power in England, he was advised by engineers who knew the country well that there was no possibility of getting it. They told him he might get 200 HP., or thereabout, but even if he found that, it would be much easier and cheaper to work with coal. In the last few years matters had greatly changed. Water-power was being used of several thousand HP., and installations were in preparation for 20,000 HP. and 30,000 HP., and there was any amount of small horse-powers which could be used to great advantage. There were many places in which 300 HP., 400 HP., and 500 HP. could be obtained, and by suitable transmission-plant, these installations would be found considerably cheaper than if the power were obtained by boilers, engines and dynamos. The idea was still held that water-power was not so cheap as power generated by coal at the pit's mouth, but it was gradually disappearing. It would be a good thing if engineers would take a lesson from the installation described by the Author, and tried to see in how many cases they could imitate it in England.

Mr. Parker. Mr. T. Parker (Wolverhampton) remarked that manufacturers were constantly on the look-out with regard to the various new applications, and they would certainly begin to manufacture if they found they were being disturbed by the multi-phase system;

but, as yet, that did not seem to be the case. There was no difficulty whatever in building continuous-current dynamos to give 2,000 volts or 3,000 volts; that was being done every day, and also transformers. The manufacturers found the demand greater than they could supply, and therefore it was hardly time for them to halt and adopt something before they were sure it was a great deal better. In comparing an installation of continuous currents with an installation such as had been described by the Author, in the particular case mentioned that system might hold its own; but if it came to be increased, he thought difficulties would soon arise which were not met with in continuous currents. For instance, no engineer would consider great extension of synchronizing plant desirable. It was known that an engineer managing an alternating-current station did not sleep so comfortably while that station was running as an engineer who was managing a continuous-current station. The use of alternating currents, if greatly extended, would mean a great disadvantage as compared with the use of continuous current. Other difficulties were met with the cables. With continuous currents there was very little induction, and there was not the same maximum pressure upon the insulators. There was far greater simplicity in the three-cable system of continuous currents than there was in the three conductors required to carry out the system in use in the Sheba mine. Induction was everywhere, and unless care was taken to balance it, as the Author pointed out, there might very easily be no current reaching the terminals at all. With continuous current only two wires were carried everywhere, except where they were taken back to the dynamos. Therefore there was no comparison between the two systems of conductors; in simplicity, and in every point that concerned practical use, there appeared to be an absolute disadvantage in the multi-phase system. With reference to the motors, an admission had been made by the Author that the double working load was a serious consideration; in fact, he sketched out a 65-HP. motor as necessary to do 50-HP. work successfully, and double torque would be a very serious matter to meet with. With continuous motors five or six times the torque could be met without damage. As to the difficulty of commutators, his firm had a great number in use, but he never heard anything about them; they went away, and people seemed to manage them easily and find no great difficulty in the matter. Another point which seemed to be fatal to the application of the system in a general way was the great idle current that was needed to run the motors without work or small

Mr. Parker.

Mr. Parker. loads. The advocates of the system pointed out that it was wattless, but that that was immaterial? Current could not be carried without conductors, and, if there was a disturbance of the whole conductor system by useless current having to be carried, copper was required. He would not recommend any mining engineer to put the induction motor, or any other motor, into a dangerous place in his mine. It could not be said that that or any electric motor was absolutely certain; it might have a mishap at any moment which might fire any ignitible gases. Cables could not be carried about indiscriminately; they must be protected carefully. With regard to pressures, it was considered by Professor Ayrton that continuous current would never be seen where great pressures were wanted. He should be very glad, however, to execute orders for 10,000 volts continuous current, and he would give a higher efficiency by the system described there, with far less complexity. As a manufacturer, he certainly looked upon the multi-phase system as one of complexity, and, therefore, he should still advocate continuous currents until more definite results were obtained.

Mr. Steiger. Mr. A. STEIGER desired to refer to the question of governing turbines for electrical transmission plants. In the early working of electrical transmission plant in Switzerland, it was very soon found that an ordinary automatic governor was unsatisfactory, and means were sought to govern the turbines in a more efficient manner, with the result that the speed was now varying not more than 4 per cent. if 25 per cent. of the full load was taken off, not more than 6 per cent. if 50 per cent. of the full load was taken off, and if the full load was taken off the turbine suddenly the speed would not vary more than 8 per cent. of the normal speed. He thought those figures were quite satisfactory and sufficient for the requirement of electrical transmission plants. The arrangement of such governors was simply the connection of the ordinary governor with a Servo motor, which was provided with a valve, and acted on the gate, admitting the water to the turbine. To give one instance analogous to the Sheba mines, he might mention that Messrs. Escher Wyss & Co. of Zürich had supplied two turbines to a mine in the Transvaal for a fall of 18 feet, each giving 210 HP. Those turbines, he believed, worked stamps in a gold mine, where exactly the same thing happened which the Author had mentioned—that part of the stamps would suddenly stop, and then the speed of the engine would increase, and there would be trouble with the dynamo. Another instance he might mention was the generating station at Davos, in

Switzerland, where four turbines worked under a fall of 330 feet, each turbine of 200 HP. The pipes were 2,400 yards long. If an automatic governor was applied under such a high fall a sudden extensive change of load would cause the gate of the turbine to be shut very rapidly, the sudden change of velocity of the water in the pipes would produce a shock, or excess of pressure, called water-hammering, which was all the more dangerous the longer the pipes. To prevent that in the first instance, there was a large air-vessel of about 4 feet in diameter and 40 feet high, connected with the main pipes, and also a special contrivance, connected with the automatic governor, to open automatically the waste-water valve, so as to allow the water to run to waste as soon as the governor acted on the gates of the turbines, and thus to remove all danger to the pipes. In that instance, if the full load was taken off suddenly, the normal speed of the turbine, and therefore of the dynamo, did not change more than 4 per cent., which he thought the Author would consider satisfactory. If water-power was used under a lower fall—and there were now many such places in Switzerland, as at Chèvres and Rheinfelden—the head of 4 to 15 metres would not be sufficient to obtain the necessary pressure for the Servo motor. In that instance a special pump was provided, which was connected with each Servo motor attached to the governor. That pump, instead of being filled with water, was filled with oil, and it served two purposes at the same time—while governing the turbine it also lubricated the foot-step. It was arranged so that the oil from the pump circulated in the foot-step passing between the plates of the foot-steps from the centre to the periphery; the pressure was about 350 lbs. to the square inch, and a thin film of oil practically carried the whole weight. In the instances just mentioned, the turbine-shaft being vertical and the dynamo directly connected with the shaft of the turbine, the load on the foot-step was about 55 tons, so that the provisions for the lubrication of the foot-step were particularly important, and justified the combination of the pump for the Servo motor with the lubricating arrangement of the footstep, and using oil instead of water. The accuracy of the governor had been found so reliable that in cases where there was a large water-power, and the water distributed over a number of turbines, each turbine was provided with its own automatic governor, and the dynamos could, without danger, be connected in parallel. Therefore, from that point of view also, he believed, as adopted in the plants mentioned, that proof had been given that the new system of governing turbines had been found efficient.

Mr. Steiger

Mr. Griffith. Mr. W. R. Griffith remarked that in England the use of electricity for the transmission of power in mines was generally confined to coal mines; the continuous-current system had been in use for 10 years fully, and its use was increasing. He would be interested to know whether there was a multi-phase electrical-transmission power-plant at any colliery in the United Kingdom? He had been enquiring for some time, but had not been able to hear of one. The advantages of the multi-phase motors were known, and he need not recapitulate them; but were there corresponding disadvantages? He had been told that he could see multi-phase generators and motors at work in Westphalia and Silesia, but he should rather like to see some at work nearer home if he could get an opportunity of doing so. Electricity as a motive power was not yet being used in his own collieries, but he was about to erect an installation of 400 HP., and he was in doubt as to whether continuous or multi-phase current was the preferable system.

Mr. May. Mr. John May ventured to think that the arrangement of the power station at Sheba was probably the only one which would have answered the purpose in view. The alternators must run in parallel to give the desired result at the mine; if they were coupled separately to the turbines it seemed certain that they would not do so, because the turbines were admittedly very bad governors; and the load came on, when the crushers were set to work, very violently and with sudden jerks. He had had a good deal of experience of parallel running of alternators, and he knew many cases where even under favourable conditions, they would not run together; and in one particular case, the worst he had ever known, there was a star-field, the Oerlikon field, similar to that of the Kapp alternators. The known weakness of this form made him think that possibly that might have had something to do with it. In one case the machines would not run in parallel, even though they were driven by ropes, which were supposed to be a very flexible form of coupling and to give special advantages. In that case it was the governor of the engine which was at fault, and it was not until about 12 months' constant tinkering at the governor that the plant could be got to work satisfactorily. He thought that was ample justification for the engineer who designed and put in that big counter-shaft. With regard to synchronizing, he should like to ask the Author if he had any difficulty in getting alternators into synchronism at the first trial with the clutches, because it seemed that there were about a thousand chances to one that the machine would not be

put into phase at the first attempt, that it was bound to slip somewhere; it could of course slip either in the clutch or on the belt, and he should like to know which form of slip the Author aimed at. If it was in the clutch the gear was a slow screw gear, and it seemed that the alternator would be likely to slip out again before it was got in. He thought Mr. Kapp's arrangement for paralleling alternators was too complicated. In electric-lighting stations it was often found that the load came on much too quickly to enable plugs and switches to be used here, there, and everywhere; in fact, as a rule the alternators were paralleled straight off. He noticed that the Author had mounted the switches on a teak base, and he justified that course on the ground that the transit to the mine was difficult. He thought if delicate instruments, such as ammeters and volt-meters and so forth, could be taken to the mine without damage, a slate could have gone as well. In fact, although he regarded teak as a very good insulating material, he had known of cases where teak boards had actually burnt up, and he should quite expect that with 3,300 volts a similar experience might be found some day at Sheba. Any one who had seen even a 2,000-volt arc with a fairly big power behind it knew what a mess it could make. In London, in the last 3 years, three works, he believed, had been burnt down simply through fires at the switchboard. He had had some slight experience of transformers in oil. He knew a works where three or four different makes had been tried, and he believed three out of the four failed. He came to the conclusion that it was due to the oil, but he had no particulars, and did not know whether he was right or wrong. Mr. May.

Mr. Alexander Siemens believed that in all discussions of the various systems of transmitting power one mistake was usually made, viz., that the advocates of any one system desired to see that system adopted everywhere, and deprecated any competing scheme and said there was no good in it. He believed the same thing was taking place in the controversy about the 3-phase system and the continuous-current motors. They both had their good sides, they both were the proper things to be employed in their proper places, and he believed that the Author had given an example of where, to a certain extent, the 3-phase system was absolutely justified. To his mind, the alternating currents—and he meant by that the machinery, transformers, cables, and everything included—had the great advantage that the currents could be generated at a low voltage and then stationary transformers, in oil or otherwise, could be used to transform up to a high voltage. It was then Mr. Siemens.

Mr. Siemens. possible to use thin conductors, which were cheap, to transmit the current to a distance where it could be again transformed down to low voltage and the motors employed at a low voltage. But he did not think that the 3-phase induction motors were very applicable in many cases. Their great drawback, about which Mr. Griffith asked, was that they really gave their best efficiency at one particular speed. The next drawback was that which Professor Forbes mentioned and the Author admitted, that if they were slightly over-worked they stopped. The continuous-current motors were entirely free from those defects. One of the speakers had said that he had tried to introduce 3-phase currents and had found that the cost of the 3-phase motor was very much higher than that of the continuous current motor, and he ascribed it to the ignorance of English manufacturers or their not being used to the things. That particular point had been the object of his careful consideration for years, and he was particularly well placed with regard to the matter, because the firm of Siemens and Halske, with whom his firm had friendly relations, although they were perfectly independent, had been very strong advocates of 3-phase currents. They had themselves established one rather large transmission of power in the Transvaal with 3-phase currents; they had also employed them in Silesia and other places, and they had been urging his firm for years to adopt 3-phase currents and introduce them into England. His answer to that had simply been that he had sent them the inquiries for transmission of power which were received by his firm from this country and from foreign countries under all sorts of conditions, and said: "Give us an estimate of what you can do this transmission of power for at 3-phase current." He had invariably found that, for any small distance like 200 yards to 1,500 yards, the continuous-current plant which his firm could supply was infinitely cheaper than 3-phase plant; but, for large distances, the calculation came out differently. The great ease with which the continuous-current motors could be regulated and run at different speeds, and the very good efficiency at which they worked when running at different speeds had induced him to be a strong advocate of always using continuous-current motors. If power had to be transmitted to a great distance, by all means let there be used for the main line 3-phase currents or 2-phase currents, or any alternating currents thought desirable, for the reasons he had already mentioned, and get the power 10 miles, 12 miles, 15 miles, or

20 miles away from the place of origin; but for the actual motors in the customers' houses continuous currents were preferable. Another reason why he advocated that was that the use of 3-phase currents for lighting purposes was not as simple as the advocates of the 3-phase current wanted to make out. The current must be always kept in the three branches exactly equal, and if that were not done there was a disturbance. Of course that did not happen if motors were used, because each motor used the three currents equally, and therefore the addition of a motor would not disturb the equilibrium, but the addition of lights did. That was the point which he found usually was not mentioned by the advocates of the 3-phase currents. Again, the plan he proposed for long distances was to use 3-phase currents, then transform them into continuous currents, and use them locally. Such a combination had been made available in Silesia, where the tramway, which was run from the central station, was worked by continuous and not by 3-phase currents. Incidentally, perhaps, he might say that, in London, the Metropolitan Electric Supply Company, he thought, was putting down a separate system of mains to distribute power by continuous currents, although they had got the alternating current handy everywhere. Then he wanted to say a word about the use of water-power in England. He did not think that English engineers were so very ignorant because they had fought shy of water-power. It was not everywhere in England that it could be used. As a matter of fact, his firm tried to light the town of Godalming by electricity driven by water-power—he was afraid almost to say the year, but he thought it was in 1882 or 1883. It was the first town, anyhow, in the whole world which was lighted throughout by electricity. It was found very soon that there was either too much water or too little, and it had to be supplemented by steam, and eventually it was entirely transformed into a steam station. Then came financial differences of opinion with the Town Council, and the lighting was abandoned. But every street in Godalming was lighted by electricity before any town in the United States, Germany, or anywhere else, thought of it. That gave him some insight into water-power. Another independent illustration which he might mention was a central station in the Transvaal put up by Messrs. Siemens and Halske, at Brakepan. It was originally designed to be a water-driven station, but after all the circumstances had been carefully considered the plans were altered and it was converted into a steam-driven station. It was all very well for gentlemen like Mr. Steiger, in a very favourably-

Mr. Siemens.

Mr. Siemens. situated country like Switzerland, where water-power could be obtained. In summer the glaciers and the snow melted and there was plenty of water and in winter it rained. In England there were droughts occasionally, and then the water-power was nowhere, and if reserve steam-power had to be used, why use water-power at all? There had been very much said about the simplicity of the induction motor, but he might remind the members, as a matter of fact, that the winding of the continuous-current motor and of the induction motor was absolutely the same. By putting three rings on a continuous-current motor and connecting the commutator plates 120° distant from each other, the three-phase motor was obtained. Of course there was the additional complication of having a commutator on the continuous-current motor; but, as Mr. Parker had said, if a commutator was properly made, and the whole machine was properly constructed, it gave no trouble. He might mention that on the locomotives which were made by his firm some years ago for the City and South London Railway the commutators had as hard work to do as could possibly be, but he did not think that any one of them had been renewed, and they had been in use now for at least 5 or 6 years. They had never been touched. That was nothing exceptional or to be particularly proud of, because any decent continuous-current constructor would make commutators like that. It was only the badly-made machines that gave trouble. Lastly, he wanted to call attention to a phrase which Mr. Griffith used, viz., that he thought it was all very fine for the people in Silesia and so on to use a 3-phase current, but he would like to see the things a little nearer home. That sentiment marked the great difficulty of introducing new things into England. Everybody fought shy of a new thing, and always wanted somebody else to pull the chestnuts out of the fire, and nobody had got the pluck to do it himself.

Mr. Beaumont. Mr. W. W. BEAUMONT desired to point out that the dynamos were designed by Mr. Gisbert Kapp as long as 4 years ago, and that English engineers could, if they had thought it worth while, have recognized fully the importance of that system. Three large firms were asked to construct the machines, and there was only one, Messrs. Johnson and Phillips, who would then undertake their manufacture. He did not know if all or either of the alterations suggested by Prof. Ayrton were made, the actual efficiency of the machines would be improved. The recognition of the system might appear to be slow in England, but all the English engineers had been busy, and it might not

necessarily be because they were unable to recognize, but that there might be doubts about the system. For some classes of work the machines were specially useful, and not necessarily superior in other work to the continuous-current machines. English engineers, as represented by Messrs. Johnson and Phillips, did, as long as 4 years ago, recognize the importance of the system. At that time Mr. Kapp was almost the only engineer in England advocating that system, which was unfavourably looked upon then; if there were any shortcomings, they might be explained by the earliness of the design. Mr. Beaumont.

Mr. Esson, in reply, said he might first answer the questions that had been asked about the alternator. Professor Ayrton asked why should such a great circumferential space be wasted? That depended largely on the type of the machine, and it mattered very little, so far as output was concerned, whether the wires were spread along the whole of the interior surface, or whether they were congregated in groups at different points. The real thing which determined the amount of wire put on the armature of the machine was the fall of potential between no load and full load, and it was very important in those machines to keep the fall as low as possible, because an alternator working on a non-inductive load, with a fall of 4 per cent., would very probably, when working on induction motors, have a fall of at least 20 per cent. The wave of the machine was not exactly of the form conjectured by Professor Ayrton. The curve was of the saw-tooth form with a slight ripple at the top forming a double peak. The rectangular form of the wires for the armature was simply to get the wires into a smaller space than the round wires would take. The reason why there were not three wires instead of four for the underground cables—in fact, why a triple concentric cable was not used instead of two concentric cables—was that the triple concentric cable created a dissymmetry throughout the whole system with two currents in quadrature and using a common return; and the way to get no bad effects due to induction was to use two concentric cables, one for one phase, and the other for the other. It was quite true that the particular field was introduced by Mr. Brown in his transmission from Lauffen to Frankfort. The only part Mr. Kapp claimed as novel in the design of the alternators was the armature, and the particular point about that was that the sectors with their coils were capable of removal. This was a high-pressure machine, whereas the Lauffen machine was a low-pressure machine, and the armature conductors con- Mr. Esson.

Mr. Esson. sisted of round rods inserted into holes in the core and insulated with paper. With regard to the breaking down of the transformers due to the oil, in the initial stage, as he explained in the Paper, there were great difficulties with the governing of the turbines, and very often the pressure ran up to twice or three times the proper working pressure, owing to their racing. The breakdowns were coincident with those two circumstances, the oil being used and those rises in pressure; in what proportion each cause contributed he could not say, but when the oil was done away with there was no more trouble. In other cases, with other transformers, similar trouble had been experienced as regarded oil, consequently it had been abandoned altogether, because, although with a great deal of care the oil might be satisfactory, it was better to do away with it when it might not always receive that care. He did not think there was any good in oil, and he believed the air-blast was superior in any case. There was this, however, about Mr. Parker's offer to transmit power by direct-current machine at 10,000 volts, that he had not done it yet, whereas on the polyphase system transmissions had been carried out at 10,000 volts, and had given no trouble. No doubt Mr. Parker would remember what difficulties Mr. Marcel Deprez had in his early experiments with direct currents at a pressure of 6,000 volts, when he transmitted power from Creil to Paris. He did not mean to say that dynamos had not been enormously improved since Deprez tried his experiments, but he was not aware that any machines had been constructed for 6,000 volts. It was not a question of alternating- *versus* continuous-current machines, the one having difficulties and the other not; but it was a question of alternating-current transmission with its difficulties *versus* impossibility, because it would be an impossibility to work at all with continuous currents some of the schemes now being operated with alternating currents. The case had been stated very well indeed by Mr. Siemens in his fair-minded speech. Polyphase currents were not to be advocated in the face of everything. Direct currents had their uses, and their sphere of use was continually increasing; but there were cases in which polyphase currents could only be used, and in which continuous currents would be quite out of place. The particular example of the Sheba mine transmission could be applied to a great many more mines, and he agreed with Mr. Siemens that for long distances in any case the transmission should be carried out by 3-phase or 2-phase currents, and that then, if necessary, it should be converted into direct currents

for distribution. He should never advocate polyphase currents for working tramway motors, because direct currents were for this purpose so much more simple; but in the particular case of the Sheba Mine it was thought better to use the induction motor as being far more suitable for the purpose than the continuous-current motor. Mr. Esson.

Correspondence.

Mr. C. F. HEATHCOTE observed that the Author had mentioned the difficulty of transport to the mining fields, and the necessity of keeping as few spare parts as possible; but he thought the difficulty of obtaining skilled labour was not sufficiently emphasized, and was seldom taken into account by English manufacturers of mining machinery. It was of greater importance than a slight increase of efficiency that all machinery intended for new or "one-mine" fields should be simple in construction, easily repaired, and suitable for constant running, by having reliable dust-, dirt- and water-proof bearings with sight-feed lubrication. Mr. Heathcote

Mr. ALFRED E. HUNT noticed that the Author referred only to copper as an electrical conductor, and desired to point out that aluminium was now, especially in the United States, rapidly finding favour in such application on account of its cost rendering it a cheaper conductor. The specific gravity of copper was 8·93, and its electrical conductivity when pure was 100 in the Matthiessen scale, but as ordinarily used in electrical conductors it was 97·61. Its tensile strength was between 16,500 lbs. per square inch and 65,000 lbs. per square inch in hard-drawn bars, and its cost was 14 cents per lb. in the United States, the equivalent selling price being 130 marks per hektogram in Germany, for wire, bars, and rods such as were used for electrical conductors. Aluminium had a specific gravity of 2·68, an electrical conductivity in commercially pure metal of 63·0, a tensile strength in pure soft wire of 26,000 lbs. per square inch, and in hard-drawn rods of wire of 40,000 lbs. per square inch. The Pittsburgh Reduction Company in the United States were selling rods, bars, plates, and wire drawn down to 0·08 inch in diameter, in large orders for electrical conductors at the rate of 29 cents per lb. at their works. This price was below the regular rate for aluminium, offered for the special purpose of meeting the price of copper for electrical conductors alone, in order to favour the adoption of aluminium for this purpose and to overcome the Mr. Hunt.

Mr. Hunt. handicap that aluminium had occasioned by its lower conductivity. It was therefore evident that (1) any given volume of copper was $\frac{8\cdot 93}{2\cdot 68}$, or 3·332 times heavier than an equal volume of aluminium; (2) the equal price of 14 cents per lb. for copper for any length of any equivalent section of aluminium wire or bar would be 14 cents times the factor 3·332, or 46·65 cents per lb., that was, 1,000 feet of wire of, say, $\frac{1}{10}$ inch diameter would cost as much if bought of copper at 14 cents per lb. or aluminium at 46·65 cents per lb.; (3) reckoning the copper conductor to have its maximum of 100 per cent. conductivity, and the aluminium to have a conductivity of 60 per cent. (which the Pittsburgh Reduction Company were ready to guarantee for their special pure aluminium metal for electrical conductors), then for an equivalent electrical conductivity a given section of copper that could be placed at 100 should be increased in area to about 160 to give an equal conductivity; (4) the relative specific gravities were such that the weight of the given equal length of the aluminium conductor with 160 sectional area will be only 48 per cent. of the weight of the copper conductor with sectional area of 100; (5) aluminium at 29 cents per lb. was therefore a more economical conductor than copper at 14 cents per lb. Taking as an illustration an aluminium conductor to replace a copper wire of about $\frac{1}{10}$ inch diameter, the aluminium wire of equal, in fact, somewhat superior, electrical conductivity would be slightly over $\frac{1}{8}$ inch diameter. The weight of 1 mile of the copper wire was 162·32 lbs., and its cost at 14 cents per lb. would be $22·72. The weight of 1 mile of the aluminium wire would be 79·46 lbs., and at 29 cents per lb. would cost $23·04. Forty-eight per cent. of the weight of the copper wire, which would give equal electrical conductivity in aluminium wire, would weigh only 77·91 lbs., so that more accurately $22·59 would be the cost of 1 mile of aluminium wire at 29 cents per lb. to replace 1 mile of copper wire at 14 cents per lb. costing $22·72. It appeared from the Paper that the Sheba line consisted of nineteen wires 0·057 inch diameter, and that the outer conductors had also nineteen wires of the same diameter, which were stranded in two segments. This copper wire weighed 9·89 lbs. per 1,000 feet. Aluminium wire of the same diameter would weigh 2·968 lbs. per 1,000 feet. Aluminium wire of equal electrical conductivity with the copper wire would weigh 4·75 lbs. per 1,000 feet. Nineteen wires in copper would therefore weigh 187·91 lbs. per 1,000 feet, which, reckoned at 15 cents per lb. as the cost for copper (and probably the rate paid for the copper delivered in Africa was considerably higher) would give a cost per 1,000 feet

of $28·19. Aluminium wire of equal electrical conductivity, each strand of which would weigh 4·75 lbs. per 1,000 feet, would weigh 91·25 lbs. per 1,000 feet. At the rate of 29 cents per lb. this would cost $26·16, or a difference of $2·03 per 1,000 feet of the nineteen-strand aluminium wire of equal conductivity to the copper. Added to this sum should be a considerable amount of saving in transport, bearing in mind that a little less than one-half the weight of the wire in the electrical conductor was required to give equal electrical conductivity in aluminium. Against this figure, however, for a case like that referred to by the Author, was the added cost for insulation and the added weight of the insulation. The actual amount of surface to be insulated, and therefore of materials to furnish this insulation, was almost exactly one-fifth. However, the cost of applying the insulation was not much greater for the larger section than for the smaller, and it had been proved by experience in the United States that about one-sixth of added cost for insulation was occasioned by the increased section of the aluminium over copper of equal electrical conductivity. Aluminium had to meet this very considerable added handicap, which did not occur where naked wires were used for conductors. It, however, only resolved itself into a question of savings and the relative advantages of the two metals for any purpose. In a considerable number of conductors in the United States in the past year the lowered price of aluminium had been cheerfully made in order to overcome this added cost for insulation. (6) The continental requirement in tensile strength for soft copper wire, rods, and bars used as electrical conductors was 22 kilograms per square millimetre, the English requirement being 14 tons per square inch, and the American requirement was about its equivalent of 32,000 lbs. per square inch. Aluminium wire, rods, and bars would be furnished of 60 per cent. electrical conductivity, which would have an equal tensile strength per unit of area with the copper, and therefore with the electrical conductivity equivalent of 48 per cent. of the weight of the copper and sectional area of 160 against the area of the copper section 100; the tensile strength of the aluminium conductors would be as 100 for the copper was to 160 for the aluminium. This would mean, if a square inch of copper conductor was used of, say, 32,000 lbs. per square inch tensile strength, the equal conductivity area of 1·6 inch of aluminium would have a tensile strength of 51,200 lbs. It had been already determined that with aerial lines the snow and ice load was practically as heavy on lengths of small wire as upon Mr. Hunt.

Mr. Hunt. larger sections, so that no objection upon this score could probably be found to the use of the larger sections of aluminium wire. Both on account of having only 48 per cent. of the weight and on account of having about 60 per cent. more strength the aluminium conductor could be used in much longer spans between supports, and the number of expensive poles and insulators could be materially diminished. Properly drawn aluminium wire was as tough and would stand bending as severely without breaking as soft copper wire. The toughness of aluminium wire was, however, greatly modified by the care and skill used in manufacture. If it was drawn too severely through the dies, or was not well annealed at the proper intervals in the drawing operation, it was finished much more brittle than when properly manipulated. Hard-drawn copper wire, especially that in the smaller sections drawn through diamond dies, was furnished with a tensile strength of 65,000 lbs. per square inch. The maximum tensile strength of the best pure hard-drawn aluminium reached under similar favourable conditions for developing the maximum tensile results had not yet been determined, but from experiments already made it could be predicted that at least 50,000 lbs. per square inch and perhaps even higher strength could be obtained. Aluminium hardened with a small percentage of alloying ingredients could be furnished in wire with a tensile strength far in excess of what could be obtained in pure aluminium. Experiments were now being made by the Pittsburgh Reduction Company to determine the alloy that would furnish the maximum tensile strength, together with maximum electrical conductivity. From results already obtained it could surely be predicted that an alloy of aluminium could be furnished which, drawn into wire, would have a tensile strength of at least 100,000 lbs. per square inch and electrical conductivity of about 50 in the Matthiessen scale, this material to rival the silicon-bronze materials which were now in use, where maximum tensile strength, together with good electrical conductivity, was required.

The power of withstanding corrosion was greatly in favour of aluminium as an electrical conductor over copper. Copper did not change in dry air, but in moist air it became covered with a green layer of basic carbonate of copper, which itself had a corroding action and did not coat and protect the underlying copper from further corrosion. Ammonia in contact with copper absorbed oxygen, and the copper dissolved in consequence of the formation of a soluble cupric-oxide and ammonia. This action was especially troublesome where copper wire was used in connecting rail-joints

in the lines of electrical railways where the ground was often subjected to ammoniacal solutions. Aluminium similarly was not acted upon in dry air, and the corrosion in moist air was of the oxide of aluminium, alumina, a harmless salt which formed an impenetrable coating on the metal and protected it from further corrosion to a considerable extent. Ammonia solutions acted on aluminium only upon the surface, attacking it and leaving behind a more resisting surface-coating of a brown colour containing silicon, which resisted corrosion from dilute mineral acids and dilute solutions of organic acids as well as moist and dry air. Subject to sulphur gases such as locomotive flue-gases, aluminium withstood corrosion better than copper. If kept free from galvanic action with any other metals electro-negative to itself, aluminium was far less easily corroded than copper. The difficulty of soldering or brazing aluminium was the chief drawback to its use as an electrical conductor. Aluminium could be soldered strongly, but it was a more difficult and slow operation at best as compared with copper, and there was much more rapid weakening of the soldered joint due to galvanic action between aluminium and the metals of the solder than with the less electro-positive metal copper. Several forms of joints had been successfully used to avoid the necessity of soldering, the best forms being to use thin aluminium sheets to wrap the joints and to twist or otherwise bind with the aluminium bars or wires to be joined. These wrapped and twisted joints with aluminium sheets could be left smooth on the outside, when desired, could be made much stronger than the body of the conductors, and were really a more serviceable job than soldered or brazed work in many cases with copper. One very practical way of making joints of aluminium-wire was to roll the thin aluminium sheet of about 6 inches width into two cylinders from opposite edges of the sheet. These double cylinders were very cheaply made on mandrils in a lathe. The ends of the wires to be joined were inserted in these cylinders from opposite ends and both the wire and sheet twisted with pliers until a firm joint was secured, much stronger than the body of the wire. The joint could readily be made impervious to the air and moisture. There were certain places where aluminium would be at a disadvantage over the smaller section of equal conductivity of copper, in ducts or conduits, where space was a considerable item. In such cases, the use of aluminium would necessarily be prevented. Aluminium, next to gold, was the most malleable of all the metals and was much more malleable than copper. Aluminium in ductility stood next to copper and was easily drawn into all sections that were Mr. Hunt.

Mr. Hunt. furnished in copper for electrical conductors. Aluminium could be furnished fully as uniform in its composition as copper. The metallurgy of copper was comparatively complicated, owing to the difficulty of converting its ores into the oxide. In most of the copper ores used, sulphur, lead, and iron were contained, as well as small quantities of other elements, as arsenic and antimony. All of these elements in metallic copper very materially lowered its electrical conductivity. The native pure copper of the Lake Superior region enjoyed the preference, due to its uniformity and freedom from impurities. Aluminium could now be furnished rivalling in purity of composition the best copper used for the purpose of electrical conductors. It had been already in successful operation as an electrical conductor for some time. The first use in a large way was with the conductors for the electric current at the Niagara Falls works of the Pittsburgh Reduction Company, where it had been used since the year 1895; the currents were of several thousand horse-power each, and of very large volume and comparatively low voltage. Both in conducting power, freedom from heating effects, power of withstanding corrosion, ease of making, wear, and efficiency of joints, the aluminium conductors had given better results than copper used for the same purpose. In the Chicago Stock Yards, a mile of aluminium wire of No. 11 gauge had been now in use for some time upon a telephone line that had been badly corroded out in copper wire, due to its being frequently subjected to sulphur gases from passing locomotives. The aluminium line was giving good satisfaction and was withstanding corrosion much better than did the original copper wire subjected to the same influence. Aluminium lines for conducting the electrical current had been placed by the Chlorate of Potassium Works at Niagara Falls, the Niagara Falls Hydraulic Power and Manufacturing Company, the Snoqualmie Falls Power Company, and the Standard Electric Company of California, with the best results. If the theory be true that the passage of high voltage alternating currents of great frequency was largely upon or near the surface of the conductors only or mainly, then the larger section of the proposed aluminium conductors would make them especially adaptable for such currents. On telephone lines, it had already been determined that as good sound transmission was obtained with aluminium of equal section as with copper, in ordinary lengths of less than 10 miles of wire. No complete results, however, had as yet been determined on long-distance telephone transmission, but the evidence would seem to point that a much less section than 160 of aluminium to 100 of copper would

give equally good results. There seemed to be no more cross-talk with the use of the larger section aluminium lines having equal electrical conductivity than copper lines. Aluminium was now being used to replace brass very considerably in the arts, as it was sold in the open market at rates which made it 10 per cent. cheaper, section for section, than brass. For electrical purposes, the metal could be advantageously used to replace brass in a good many ways. Commercially pure aluminium, as furnished to-day, contained less iron than commercial brass, and was therefore more non-magnetic than brass. The electrical conductivity of aluminium was far superior, section for section, to brass. Almost every electrical apparatus of present construction, in which an iron core —usually a laminated iron core—was used in motors, generators, or transforming machinery, had spaces for ventilation, and the spacing was made by the means of drawn bars, flat rods, or angles or tee-shaped pieces. Brass had been almost invariably used for this purpose in the past, probably on account of its non-magnetic properties as compared with iron or steel. Drawn aluminium sections could be furnished at a cost 10 per cent. lower than brass, section for section, and on account of the lightness of aluminium, it could be advantageously used. Mr. Hunt.

Mr. Gisbert Kapp, who was responsible for the design of the Sheba transmission plant, thought the reasons which had induced him to select the 2-phase in preference to the 3-phase system might be of interest. The latter required about 25 per cent. less copper in the line, the generators and transformers were cheaper, and the motors were slightly more efficient. It might, therefore, at first sight seem to have been a mistake not to select the better system. The Author spoke of authorities having advised 2-phase plant. If the Author referred to Continental manufacturers of alternating-current plant, they had strongly urged in their tenders the adoption of 3- instead of 2-phases, and English firms refused altogether to tender for a polyphase system, the only exceptions being Messrs. Johnson and Phillips. This fact showed that, at the time the Sheba works were designed, the general body of English engineers, so far from advising or approving 2-phase transmission, were actually opposed to it. Yet this system, and also the 3-phase system, had now obtained a firm footing in England. There were several reasons why he adopted the 2-phase instead of the 3-phase system, notwithstanding the general superiority of the latter, the principal of which concerned the line. An overhead transmission line, for continuous current in the same locality, having been frequently struck by lightning, it was advisable to Mr. Kapp.

Mr. Kapp. protect the new line by placing it underground. In those days triple cables were not made twisted, but only concentric, and the jointing of such cables was too difficult to risk repairs being made by a local staff. The only safe plan was to use simple concentric cables, and these could not convey a 3-phase current. Another reason for adopting two phases was the desire to obtain the whole of the plant in England. At that time no firm in England had carried out any polyphase work, and it was doubtful whether any firm would, for the sake of one special case, enter on a totally new line of construction. It was, therefore, expedient to so draw the specification that firms tendering might use existing patterns of apparatus with some slight modifications, that is to say, supply a polyphase generator which should be nothing else than a combination of single-phase machines. This expedient would obviously be the more easily adopted the smaller the number of phases. Finally, there was the question of repairs. These could be the more easily effected the less the windings overlapped, that was, the less the number of phases. For this reason the generator adopted was not a 2-phase machine proper, but a combination of two single-phase machines. There was no overlapping of windings, and each coil was an independent unit easily renewable. Although a machine wound for three phases with overlapping coils would have been some 30 per cent. lighter and 20 per cent. cheaper, the greater weight and cost of the adopted design was more than made up by the important advantage that repairs could be rapidly executed by workmen without special skill. The Author had scarcely done justice to the excellent quality of oil as an insulating medium for transformers. His explanation for the failure was correct, but his remedy of discarding oil altogether was needlessly heroic. Oil was largely used as a filling for high-pressure transformers in America and on the Continent of Europe. Two conditions must, however, be observed. The oil must be of the proper kind, and there must be a head of oil over the transformer case. This could best be obtained by a standpipe in the cover terminating in a vessel of sufficient capacity to permit free expansion and contraction of the oil with change of temperature. The threads of moisture, to which the Author referred, occurred only at the surface of the oil, and if the latter never left the expansion vessel, no convection of moisture by stream lines could take place.

Mr. Lewis. Mr. J. Slater Lewis remarked that for the successful adoption of electrical transmission of power that system must be chosen which, in view of all the surrounding conditions, was the simplest

and most efficient, involved the least capital outlay, was most competent to withstand overload, was the least costly to maintain, and the least likely to cause delay through breakdowns. It was shown in the Paper that power might be successfully transmitted over long distances by the 2-phase system, but whether the ultimate distribution of the power would be better attained by stationary transformers and induction motors, or by rotary transformers and direct-current motors, the Author had not attempted to prove, nor had he drawn conclusions as to the relative efficiency and cost of those two systems. Nor were the disadvantages arising from the overloading and "pulling up" of these induction motors dealt with, and no statement was made as to breakdowns, cost of repairs, and cost of the spare plant which had been installed as a safeguard to stoppages due to breakdowns. In determining the simplest and most efficient system due regard was necessary to locality, repairs, and cost of working. For instance, the transmission of power plant which would be eminently satisfactory for a modern engineering works, with an efficient electrical staff, or within a short distance of a dynamo manufacturer, would be altogether unsuitable for foreign mining purposes in a district hundreds of miles away from a repairing shop, and in the former case it might not be considered a serious risk, whatever system were used, to run the works without duplicate parts, whereas in the latter case, unless a full set of duplicate parts were kept (and even they were easily repairable), a whole mine might, in the event of a breakdown, be entirely or partially crippled in its operations for months. Other things being equal, therefore the best commercial system was that which needed the least number of duplicate parts, and where the machinery might be repaired with the greatest facility and at the least cost and inconvenience. The liability to breakdown in the system advocated by the Author might be practically nil, but it was well known that the best electrical plants were liable to breakdown, not through bad workmanship or bad materials, but through rough usage, accidents, and other causes altogether beyond the control of the dynamo maker. No engineer, therefore, responsible for the continuous working of a factory or any other industrial establishment, would care to undertake the responsibility of running under circumstances which might possibly lead to a suspension of business for a very considerable period of time. The question of duplicate parts, overloading effects, and the cost of repairs, should therefore be seriously taken into account when a transmission of power scheme was being considered. The system which formed

Mr. Lewis.

Mr. Lewis. the subject of the Paper was as yet in its infancy, and though plant constructed upon that system might have run satisfactorily for a couple of years, it yet remained to be seen whether, for distribution purposes, at any rate, it might be regarded as better from every or any point of view than its rivals. No information was given by the Author upon which it was possible to base a comparison as to capital outlay. An instance of sound financial judgment in the selection of driving power was to be found in the Lancashire cotton industry, where the mills ran continuously year in and year out with very great efficiency, and with a very small percentage of time lost through breakdowns. This was largely accounted for by the fact that the profits were so small that only plant well known to be suited to the requirements, and which warranted very few, if any, spare parts, dare be employed. It would be possible to drive such mills with high-speed engines, and, of course, by electricity, but in considering an estimate for such methods of driving a cotton mill the owner would enter seriously not only into the question of first cost, but more particularly into the question of contingencies, namely, the probabilities of breakdowns and spare parts involved, cost of repairs and maintenance, and the skill required in effecting repairs and maintaining the plant in a state of high efficiency. The plant decided upon should therefore, though not necessarily, compare favourably with other systems in point of first cost and its liability to breakdown, and the cost of maintaining it in a state of efficiency and of promptly effecting repairs should be above question. It was properly pointed out by the Author that a good margin of power was essential in the motors, and that a 50-HP. motor ceased to respond to the increase of load when the power approached 65 HP. He also stated that in large motors it was necessary to adopt devices to prevent an excess of current in starting and its consequent evil effects on the even working of the plant. He further admitted that if the pressure at the motors was allowed to fall, larger currents were required in the rotor conductors to develop the power, and such currents reacting on a weaker field actually reduced the margin of power available. With an irregular load also a large margin was stated to be necessary, and even then the fuses occasionally melted, owing to the carelessness of the natives admitting heavy pieces of rock in the crushers. He did not hesitate to state that for many mining purposes the use of these induction motors, requiring such refinements in the matter of electromotive force, and with such a small margin of power, would lead not only to very considerable risk to life and property, but also to very

serious loss and inconvenience in working. His opinion was applicable to many other cases, where it was well known that the normal load of the motors was frequently exceeded by as much as 100 per cent. to 200 per cent., and that for periods varying from a few minutes to 1 hour or 2 hours overloads of 25 per cent. to 50 per cent. are of regular occurrence. It would appear, therefore, from the Author's remarks that induction motors would be quite unsuitable for many purposes, unless very large sizes were installed, when the question of cost and efficiency at normal loads would have to be encountered. He was surprised to find in the generator a method of fixing the armature coils which was not only unmechanical, but in the event of its being found necessary to remove any coil, say two or three times, it would probably lead to the destruction of the tips or horns of the sectors, which in a remote foreign country could not be replaced except at very considerable cost and probably at serious inconvenience. In other respects the generator appeared to be thoroughly sound in design and construction, and with a clearance between the armature and fields that would commend itself to those who had experience in this connection. With respect to the motor, whilst the rotor was the acme of simplicity and embodied features which must appeal to all dynamo manufacturers, the stator had a very costly and complicated "interlaced" winding, which in the event of a short circuit or an earth, would probably lead not only to a serious delay, but to a most expensive repair at the hands of a skilled armature winder. It would be observed from *Fig. 8* that the stator and the coils formed practically the body of the machine and were inseparable even for the purpose of erection, and that in the event of a breakdown the repairs would have to be carried out *in situ*, the motor meanwhile standing, or another machine provided to replace it. This practically meant that an entire motor would have to be kept as a standby, unless delay were of no consequence. The worst that could possibly happen to a direct-current motor was a fault in the armature or field-coils, which could be at once replaced, if spare parts were at hand, and repaired without difficulty. The Author had not given the clearance between the rotor and the stator, but it was well known that the smallest possible clearance between these two parts was necessary to successful and efficient working. Mr. Ll. B. Atkinson[1] had stated that the clearance between the armature and inducing core must be as small as possible, and that in Continental practice it did not exceed, say, ½ millimetre for 10-HP. motors, and 1 millimetre for those of Mr. Lewis.

[1] Minutes of Proceedings Inst. C.E., vol. cxxxiii. p. 159.

Mr. Lewis. 100 HP. He further stated that in American practice the clearance was greater, and that although it led to a smaller value for cos ϕ it was more satisfactory from a mechanical point of view. It was also well known that the rotor must be maintained in a position absolutely concentric with the stator, not only because mechanical injury to both parts would follow in the event of their fouling one another, but because the efficiency of the motor and its starting properties would be very seriously affected were not concentricity of the parts absolutely maintained. This point in connection with induction motors was of great importance, even where the machines were in the hands of skilled engineers. In the case of the motors referred to in the Paper, no provision appeared to have been made for adjustment of the rotor bearings, and though the clearance between the armature and fields of the generator had been given, and such clearance was to be observed in the drawings, none was to be observed in the drawings of the motor. It appeared, therefore, that the question of clearance in these induction motors was a point about which the designers thought it prudent to say as little as possible. Taking everything into consideration, he was of the opinion that, for mining purposes, in districts where skilled labour of the class required in this case would be unobtainable, except at great cost and delay, the motors recommended by the Author were not so well suited to the work as the direct-current motors of modern design and construction, where there was no more trouble with sparking at the commutator than there would be with a third bearing, or with the collecting rings and brushes of the 2-phase motor. In well-designed and thoroughly efficient direct-current motors with slot-wound armature, as made by leading electrical engineers, there was ample starting power, plenty of clearance between the armature and the pole-pieces, and liberal provision for overloads, whilst the element of spare parts, cost of repairs and general maintenance, was such as would commend itself to practical mining engineers. It would appear, therefore, that the installation at the Sheba Mine would have been better if a rotatory transformer had been used instead of a stationary transformer, and the current distributed to direct-current motors of the enclosed type. The latter system of working had hitherto commended itself to all electrical traction engineers, who would gladly have used multiphase motors for traction purposes if they had felt thoroughly convinced that their application would not lead to trouble. For the transmission of power in ironworks, collieries, saw mills, and similar undertakings, where the distances were not generally of much moment, and where existing engines had

frequently to be used, and which generally had defective governing arrangements, a direct-current system would be distinctly preferable to the one advocated by the Author, inasmuch as the capital outlay would be no greater, whilst the cost of maintenance and delays in running would be found distinctly in its favour. Though his firm had erected some hundreds of dynamos and motors for the transmission of power under all conditions, there had not been a single case of serious breakdown or delay of any kind, except from causes which were quite accidental and that were common to any system. It was difficult to see how any possible advantage could be gained by the use of a new type of motor in which there were serious electrical and mechanical defects, and which in point of efficiency and simplicity could not successfully compete with the thoroughly practical and well-tried direct-current motor as now manufactured. His experience was that what was wanted by the every-day purchaser was not a system involved in nice electrical refinements and pretty mechanical devices, with microscopical adjustments, but one where there was good workmanship, sound practical mechanical engineering, liberal allowance for fair wear and tear, and an entire absence of those costly and troublesome contingencies which had done so much towards retarding the progress of the electrical engineering industry. Mr. Lewis.

Dr. COLEMAN SELLERS observed that the Author's use of polyphase induction motors for the purpose in question was certainly warranted by experience in the United States, and the 2-phase system adopted by the Cataract Construction Company in work for the Niagara Falls Power Company had proved eminently satisfactory. The slow introduction of Mr. Nikola Tesla's inventions had in no way been due to want of merit, but to the conditions that existed when he was experimenting for the Westinghouse Company. At that time the highest frequency obtained in general practice, for the reason that the early alternating-current generators were made from machines built for direct-current and converted into alternating-current generators by leaving off the commutators. They were then driven up to the greatest speed possible within the limit of safety. It was some time before the frequency was studied on lines of efficiency and economy, and it was not feasible to get high efficiency with high frequency. The Niagara Falls plant worked at only 25 alternations per second, and it was not until the installation of other multiphase plants besides this created a market for induction motors, that there arose occasion for manufacturers to carry this class of machines in stock. When the demand was Dr. Sellers.

Dr. Sellers. created it was filled at once, and the machines were as efficient as the best direct-current motors, with the additional advantage of being adapted to high voltage with safety, on account of these motors having no live terminals and no commutators and brushes to keep in order and no sparking to prevent their use, even where gas of an explosive character was likely to be met with and where it was desirable to install the motors in the interior of the mines. In his own experience there was no market in the United States for induction motors in 1888 and little in 1893, but now the demand was very great, and the construction of machines was becoming constantly improved. He was confirmed, however, in the belief that for the transmission of power the low frequency had great advantage except in the case where light was the prominent feature.

Mr. Weiss. Mr. CHARLES WEISS thought, with regard to the system used for transmission, it would be interesting if the Author had mentioned the authorities who had been consulted by the engineers at Sheba, and if he had given the reasons which led to the adoption of 2-phase currents. There was no doubt that induction motors were superior to continuous-current motors, both as electrical machines and also in view of the marked advantages gained by the absence of commutators and brushes. At Niagara 2-phase generators were used, the current being transformed to 3-phase for use at the motors. In view of many other advantages which the 3-phase system possessed over the 2-phase system, it appeared extraordinary that the authorities at Sheba did not apply the former, which they would find working so well at Moodie's Mine, Barberton, and at least four other mines near Johannesburg. The latest large power transmission in Europe—at Rheinfelden—was very carefully planned, and although both 2-phase and 3-phase currents were considered, the greatest advantages lay with the latter. Under the same electrical conditions, there was a small percentage more energy obtainable when using 3-phase currents, and there was saving in conductors, transformers, and motors. For the same electromotive force, the same power, and the same losses in transmission, there would be, in a 2-phase plant, either four conductors of, say, 50 square millimetres each = 200 square millimetres, or three conductors (one as a common return), two wires at 50 square millimetres and one wire at 140 square millimetres = 240 square millimetres. For 3-phase transmission, on the other hand, only three wires, each 50 square millimetres = 150 square millimetres, were required. In constructing transformers, too, the advantage lay with the 3-phase

system, since all the necessary windings could be placed in one apparatus, whereas, as the Author mentioned, for safest working with two phases, four transformers were necessary, two for each phase. The small motors at Sheba were wound for 2-phase currents, at 100 volts per phase, and for the larger powers a 3-phase arrangement of starting resistance was provided. The advantage of the 2-phase winding was difficult to appreciate, as with more windings there were naturally greater internal losses —due to greater dispersion of lines of force—than in a 3-phase motor with a simple "star" winding. He had recently had the opportunity of seeing several plants erected by the General Electric Company of Berlin, who had already installed 90,000 HP. in 3-phase machines, including 600 HP. at Barberton, 670 HP. at Johannesburg, and 10,800 HP. at Rheinfelden, and he was convinced that both theoretical and practical considerations pointed to the 3-phase system as the most economical and reliable for power-transmission. Mr. Weiss.

Mr. W. B. Esson, in reply to the Correspondence, agreed as to the desirability of having all the electrical machinery employed in mining work of the simplest possible construction, and he had always kept this point in view and emphasised it most strongly. It was implied by Mr. Kapp that 3-phase transmission was better than 2-phase; but he greatly doubted if this was the case for mining work, where the current had to be distributed to a number of motors of different sizes placed at a considerable distance apart and used also for lighting. Where the power had to be transmitted over a long distance there was a saving of 25 per cent. in the copper conductor if three phases were employed instead of two; but each case had to be considered on its merits, and it was impossible to determine, until all the circumstances were known, whether for a given transmission two phases or three phases were preferable. In an underground cable the reduction of cost would not be proportional to the saving of copper, while a triple concentric cable was not objectionable only on account of the difficulty of jointing, but because when carrying 3-phase currents dissymmetry would be produced throughout the whole system, owing to the difference in capacity and self-induction of the three conductors. In the polyphase generators now built there was the same amount of overlapping in the windings, whether they gave 2- or 3-phase currents, though the number of poles in the two cases was different; but it was a mistake to suppose that satisfactory 3-phase generators with overlapping coils could have been made 30 per cent. lighter in weight than the Sheba machines. Mr. Esson.

Mr. Esson. The machines would have been about the same weight, but the fall of potential between no load and full load would have been much less; and this was the direction in which improvement was sought, the primary object being to get a small fall of potential rather than diminished weight. He agreed that a system should always be chosen which, in view of all the surrounding conditions, was the simplest and most efficient, involved the least capital outlay, was the most competent to withstand overload, was the least costly to maintain and the least likely to cause delay through breakdown, and it was consequent on weighing up all these circumstances that the 2-phase transmission, as described in the Paper, had been adopted for the Sheba Mine. As regards the amount of overload which would draw up the motors, very great improvements had been effected in the construction of induction motors during the last 4 years, and they were now made so that they would withstand—the larger sizes 50 per cent. overload, and the smaller sizes 100 per cent. overload. He had advised the employment of no particular motor under all circumstances. Both induction- and direct-current motors had their uses, and the former should not be altogether condemned because Mr. Slater Lewis' experience had been confined to the latter. The 3-phase installation at Moodie's Mine, and other installations of the same class near Johannesburg, were all subsequent to the installation at Sheba, which was the first on the alternating-current polyphase system in South Africa. The extremely unsatisfactory working of the first power installation at the Moodie Mine, on the direct-current system, was not without influence in determining the adoption of alternating current for the neighbouring Sheba Mine. The relative value of two phases and three phases, he would reply, was not determined wholly by the saving of copper in the line; many other considerations had to be taken into account, and neither could, under all circumstances, be considered preferable.

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22 November, 1898.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

The President. The PRESIDENT said he had no doubt that every member present had seen the announcement of the death of the oldest and senior Past-President of the Institution. He need not tell the members that it had been received by the Council with great grief. They

had accordingly passed the following resolution:—"That the Council have learnt with deep regret of the death of their distinguished Past-President, Sir John Fowler, Bart., whose interest in the welfare of the Institution had been maintained during 54 years of membership, he being at the time of his death the Senior Past-President, and desire to express to Lady Fowler and the members of the family their sincere sympathy in the loss they have sustained." That resolution would be forwarded in due course to the family, and would be taken as an indication of the deep sympathy which the whole Institution felt in their sad bereavement. The President.

The discussion upon the Paper "The Electrical Transmission of Power in Mining," by Mr. W. B. Esson, was continued and concluded.

29 November, 1898.

JAMES MANSERGH, Vice-President,
in the Chair.

(*Paper No. 3106.*)

"The Effect of Subsidence due to Coal-Workings upon Bridges and other Structures."

By STANLEY ROBERT KAY, Assoc. M. Inst. C.E.

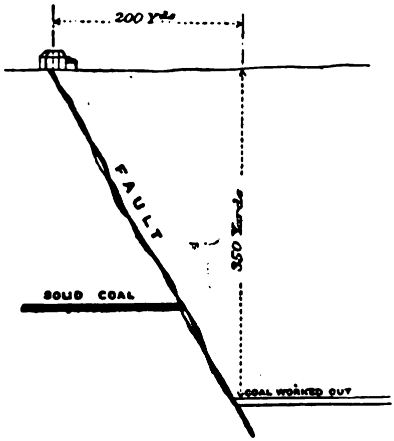
THE coalfields of England form centres of great industries, equipped with all the means of rapid intercommunication and transit that engineers can devise; so that lofty buildings, heavy bridges, or costly tunnels have often to be constructed in situations where workable coal-seams are known to exist, and, it may be, have actually been worked or are being worked. It is therefore necessary, before designing works in such situations, (1) to know the principles of subsidence following the working of the coal, as a guide to the position and character of the works; (2) to have approximate knowledge of the area of coal necessary to be left unworked to protect the structure about to be designed, supposing the coal not yet worked; and (3) to suit the design to the supposition that the coal may afterwards be worked out without any solid pillar being left for the support of the surface.

The general effects upon the surface of removing a seam of coal, of varying thickness and depth, will be first considered, both with regard to the actual subsidence resulting therefrom and the time required for its operation. It is unnecessary to point out that subsidence always follows coal-working. It is evident that, the support being removed, the superincumbent mass must sink, to a greater or less extent, dependent upon the thickness of material excavated. Certain geological factors qualify this axiom, such as beds of rock of greater or less thickness, faults &c.; but generally the subsidence is proportional to the thickness of material excavated. The depth below the surface approximately regulates the duration of the movement. Those geological con-

siderations have at times an important bearing upon both the amount and the manner of subsidence. Where thick and massive beds of sandstone occur between the coal and the surface, as, for instance, the Pennant rocks of the South Wales and Bristol coal-fields, the subsidence is very gradual, and, in the case of a thin seam, almost imperceptible, though in that of a thick seam it is sometimes severe and eccentric.

When, during the working of coal, it is found necessary to remove a portion of the overlying shale or clod, this rubbish is used for stowing and wall-packing the excavated area, to avoid the expense of bringing it out of the pit; in some cases material is taken underground from the surface in order that the wastes may be packed particularly tight over a special area; where this is done to a large extent, it follows that subsidence is considerably modified, and the damage to the surface in the case of shallow mines is considerably diminished. It is not, however, practicable in all cases to pack the wastes very tight, and the removal of the coal in shallow mines down to, say, 50 yards in depth, causes the overlying strata to give way occasionally quite up to the surface; cracks are formed traversing lines of weakness in the strata and wrecking any rigid structure in their course.

Fig. 1.



Even in the case of deeper mines, where subsidence seldom causes fracture of the surface, the lines of faults are lines of weakness; and where the coal has been worked off to a fault underground, it not infrequently happens that damage occurs to structures upon the surface-line of such a fault, in some cases a considerable distance horizontally from the line of fault in the coal, owing to its hade or inclination. The lateral support of the strata loses its continuity at the fault, and though vertically below there may be apparently a sufficient area of solid coal, it has no effect in preventing subsidence upon the other side of the fault.

An example from actual practice, *Fig. 1*, illustrates the danger to be apprehended from coal-workings near a line of fault. The working of the coal on the lower side of the fault at a depth of

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350 yards (though only 3 feet in thickness) induced subsidence which extended to the line at which the fault was found at the surface, 200 yards horizontally from the point vertically over the nearest coal-workings at the fault. Unfortunately a valuable house stood upon the line of fault, and it was greatly damaged. Lines of fault at the surface are therefore to be avoided in the erection of permanent works even if pillars of coal are purchased for support, as it is impossible to ensure against a possible "drag" or "pull over" of the strata, unless an abnormally large area of support is secured; and this upon the score of economy is inadvisable.

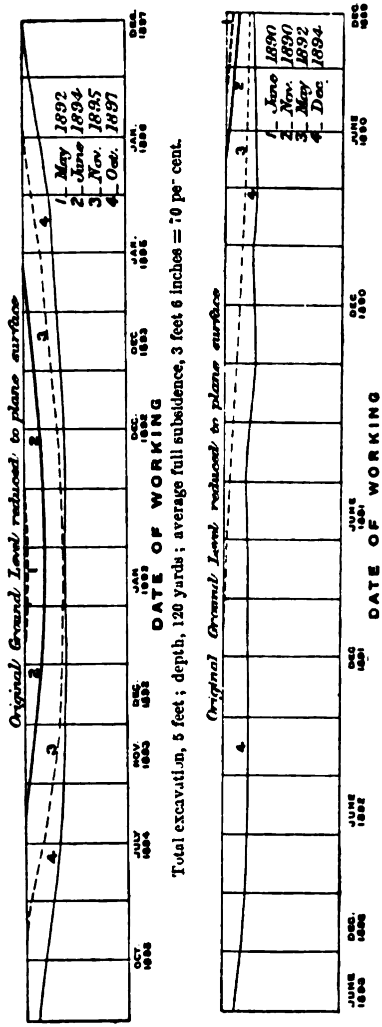
In the case of an area free from faults, and where the strata are horizontal, or nearly so, the subsidence following the working of coal is a simple mechanical problem, in which few disturbing factors have effect. There is a direct vertical subsidence varying in amount between one-half and two-thirds of the thickness of material excavated—generally the former, but in cases where material for "packing" purposes is scarce and the goaf extensive, the latter ratio is reached. The subsidence from the working of shallow mines down to, say, 100 yards in depth, is felt at the surface within a period varying between a few weeks and a few months, according to the depth and thickness of the seam and the character of the overlying strata. Breaks in the strata seldom find their way to the surface from a depth of 100 yards unless the thickness of the seam worked is considerable and there is a thick bed of rock intervening. The Author is aware of instances of coal-seams up to 5 feet in thickness being worked out beneath canals and rivers at this depth, without the slightest percolation resulting; care having been taken in the packing and stowing of the goaf to reduce the amount of subsidence as much as possible. The time taken for complete subsidence at this depth may be between 2 years and 3 years, varying as already stated. In the case of mines more than 100 yards in depth, the subsidence follows more slowly the greater the depth and the less the thickness excavated, as might be expected.

The Author some years ago took levels extending over a period of 5 years on the surface of a portion of two separate colliery royalties, at depths of 120 yards and 330 yards, with a view to obtain reliable evidence as to the commencement, duration, character, and amount of the subsidence. The locality chosen in each case was fairly level, the strata, in addition to being nearly horizontal, being free from faults of any magnitude; and was of the average coal-measure character of alternating binds

and shales, &c., free from massive beds of rock. The results, *Figs.* 2, indicate that in the working of the 5-foot seam at a depth of 120 yards the subsidence closely followed the working of the coal, that it continued for 3½ years, and that it amounted to practically 70 per cent. of the thickness excavated. The working of the 3-foot 6-inch seam at a depth of 330 yards gives similar results; though varied by the additional depth and smaller thickness, as to the time of the commencement and the duration of the movement. The subsidence followed the extraction of the coal in about 6 months' time, continued during 4 years, and amounted to 64 per cent. of the thickness excavated. In both cases the movement was uniform, without breaking the surface.

With deeper mines the effect of subsidence is felt more in the nature of a "pull over," in the case of buildings, than an actual downward movement, *Fig.* 3. The strata appear to bend back over the goaf in a curve of radius depending on the depth, and thereby subject the strata overlying the recently-worked area to a strain (rendered partly passive from the move-

Figs. 2.



Total excavation, 5 feet; depth, 120 yards; average full subsidence, 3 feet 6 inches = 70 per cent.

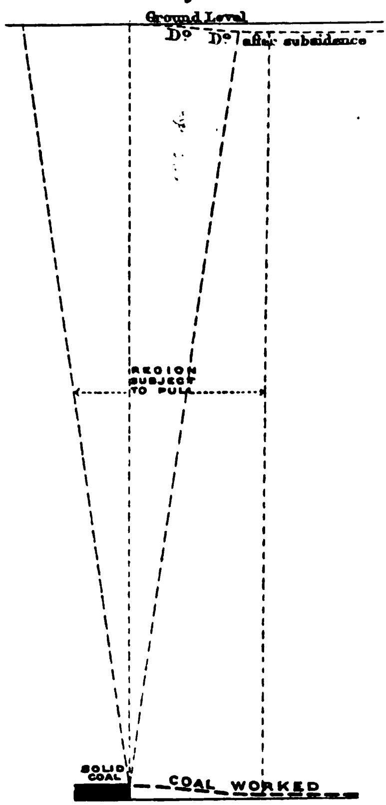
Average total excavation, 4 feet; depth 330 yards; average full subsidence, 2 feet 7 inches = 64 per cent. The variation in the subsidence is due to the variation in the thickness of the clod overlying the coal, removed in course of working.

Horizontal Scale, 1 division = 1 chain; Vertical Scale, 1 inch = 16 feet.

DIAGRAMS SHOWING OBSERVED DIFFERENCE OF LEVELS DUE TO SUBSIDENCE.

ment of the face) coincident with the progress of the working face, and, owing to its great radius and its slow movement, doing very little damage to surface structures of ordinary character, as a rule. Should, however, the movement of the faces be arrested from any cause, the probability is that any structure over the line of the working face, or near enough thereto to come within the influence of the now active pull, will in time sustain considerable injury. This principle was well illustrated during the coal strike of 1893. A coal seam 6 feet in thickness was being worked in an extensive long-wall face at a depth of more than 600 yards, and it was thought under the circumstances wiser to take out all the coal in a moving face than to leave a large area of valuable coal as a pillar. Before however, the faces had reached a point vertically beneath the buildings, the miners' strike caused the working to cease for 5 months, and during that time, no doubt owing to the active assertion of the "pull," the building was wrecked. It is possible this might have happened had the working not been arrested; but the Author believes that it was the bringing of the passive part of the pull into active play that did the mischief.

Fig. 3.



The Author has endeavoured to trace to their sources many cases of damage resulting from working coal, even after what was considered a sufficient pillar had been left for protection, and his experience shows that subsidence is most irregular in its action as regards damage to surface erections. In some cases it was found that the "pull over" had threaded its way along lines of weakness in the natural joints and breaks of the rocks until, when it had reached the surface, it had invaded the site of the structure that the pillar was intended to protect. In

another case, where there was a bed of rock 20 yards thick about 50 yards below the surface, and coal 7 feet thick was worked at a depth of 270 yards, the subsidence on each side of the pillar seemed to break the rock, and to do far more damage than if the coal had been swept quite out. In another instance, at a depth of 210 yards, the pillar was worked half way round, and was then left for some years. When the coal on the other side was worked, the "pull" in the opposite direction seemed to break the pillar, and damage to the buildings followed. On the other hand, it has been found that pillars in themselves apparently absurdly small have proved sufficient, and structures, in places where from the position of the workings it was thought damage would certainly ensue, have escaped unharmed. These varying examples of the freaks of subsidence are only a few cases out of many where the general principles were otherwise upheld. They show, however, that no absolute formula can be enunciated to apply to all cases with regard to the size and position of the support necessary. All rules for that object are therefore of an empirical character, and local considerations may modify or qualify the formulas based upon generally accepted principles.

It will now be expedient to treat the three heads mentioned, into which the subject appears to the Author naturally divided, and to apply the rules of modern practice in further detail.

The Principles of Subsidence following the Working of the Coal as influencing the Position and Character of the Works.—In this case it is assumed that the coal has been worked. If the site of the intended works be over a fairly extensive area of goaf free from large faults, it may be assumed, if the coal be 100 yards or more in depth, that subsidence when complete will leave the surface much as before, though at such a lower level as is represented by, say, 66 per cent. of the gross excavation. The time necessary for complete settlement varies according to the local conditions previously described; but 2 years or 3 years at least should be allowed after the removal of the coal before works of an important and rigid character are commenced. In the case of an ordinary road or railway bridge or viaduct, any form of arch should be avoided. Well-bonded piers, abutments, and wings, and steel superstructure are the best factors of safety to adopt, the latter having the requisite elasticity to adapt itself to any slight movement subsequent to erection.

When the site of the works is otherwise situated, regard must be had to the position and size of faults met with in working the coal, and the position and direction of the same must be ascertained at the surface, if the throw is of any serious amount. Such lines of

fault are to be avoided in setting out the works, if at all possible. Should the site be near the limit of the workings, as at a boundary or barrier, and yet over the goaf, it will be necessary to exercise care in the event of the coal not being very deep, to allow full time for subsidence to take place and for any break in the strata to show itself; and in the case of deeper mines to give time for any "pull over" to exhaust itself. It is better, however, for such positions to be avoided, if possible.

Waterworks and reservoirs present many complicated problems in mining districts, and have been the cause of costly litigation. Where practicable they should not be situated in such districts, if a certain height of the embankments and other permanent works is to be maintained, unless the suitability of the site outweighs the cost of purchasing large pillars of coal for their protection. The extraction of the coal underneath canals necessitates the puddling and raising of the banks and towing-path. In some cases this has been done to a considerable extent, when more than one seam is worked, though it is usual to purchase support for the locks to maintain the water-level at those points. All works, therefore, necessarily situated over recent goaf should be removed from faults and goaf-edges, should be well tied and bonded in construction, and arches should be avoided.

The Area of Coal required to be left Unworked for Protection, supposing the Coal not Worked.—In the case of horizontal mines, or those only slightly inclined, the theoretical line of break or subsidence is vertical or thereabouts. In practice this is found to vary on account of the natural lines of weakness in the joints and bedding of the strata, inducing the movement to vary from the perpendicular either to one side or the other within the limits of the effect of the subsidence. It will be necessary therefore in laying out the pillar to allow for the possible spread of the "pull" during the movement. The strata being horizontal, or nearly so, the pillar will surround the structure equally on all sides.

In order to ascertain as nearly as possible the best pillar to leave, having regard to both the thickness of the excavation and the depth below the surface, the Author has deduced an empirical formula from many examples of modern practice coming within his experience during the past 15 years, giving in the result a kind of standard gauge, merely requiring modification according to the exigencies of the case. It gives the necessary pillar under normal conditions—special or local considerations may vary the dimension arrived at by its means—but generally it

gives a sufficient area of support, with a view to the possibility of the pillar being "ribbed" or partially worked, as afterwards explained, at depths exceeding 300 yards.

Let d denote depth in yards; t thickness excavated in feet; and r radius of support in yards;

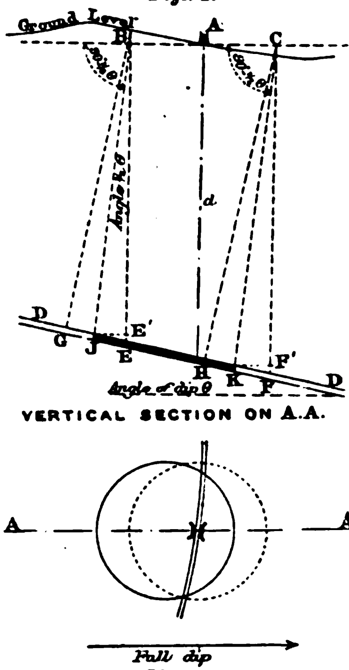
then $$r = \frac{\sqrt{3\,d} \times \sqrt[3]{t}}{0 \cdot 8}.$$

For example, an arched bridge over a road or railway requires support. The depth of the seam is, say, 400 yards. The thickness of the material excavated, say, 4 feet, then—

$$r = \frac{\sqrt{3 \times 400} \times \sqrt[3]{4}}{0 \cdot 8} = 68 \text{ yards};$$

or a pillar of 68 yards radius left all round the structure will give the support necessary under normal conditions.

Figs. 4.



Displacement of Pillar due to Dip.

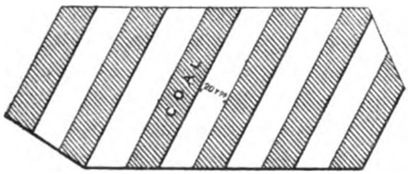
When, however, the strata are inclined appreciably from the horizontal, although the size of the pillar, as given by the above formula, is sufficient, its position with regard to the structure it is designed to protect requires consideration. It is often assumed that subsidence under the condition stated takes place at right-angles to the dip, as in horizontal mines; and again, that it takes place vertically, as being directly due to gravitation. The Author, however, believes that a line midway between the two gives the more general line of break—that is to say, supposing the angle of dip to be θ, then the angle that the line of break makes with the horizon is $90° - \frac{1}{2}\,\theta$, as shown in *Figs. 4.*

In laying out upon a plan a pillar for the support of a bridge, as in *Figs. 4*, to be left in inclined seams up to 30°, the size of pillar necessary may be calculated by the formula given. Marking this, upon the plan, round the bridge, the position of the pillar is given supposing the measures to be horizontal. Its

lateral displacement to the high side due to the inclination, at a depth d, is $d \tan \frac{1}{2} \theta \cos \theta$. This lateral displacement may be graphically determined as shown in the vertical section on the line of dip.

Let A represent the bridge to be supported by a pillar to be left in the coal D D at a depth of d yards. Calculate the size of the pillar from the formula given, and mark it upon the horizontal line at B and C drawn through the ground-level at A. Draw B J and C K, making an angle of $90° - \frac{1}{2} \theta$ with the horizon from B and C respectively. Then J E and K F represent the lateral displacement due to the dip in the coal, and J E′ and K F′ the displacement in plan. This is shown in the plan, where the dotted circle represents the position of the pillar when the coal is horizontal, and the circle in a full line its position corrected for dip.

Fig. 5.



PLAN OF PILLAR PARTIALLY WORKED BY MEANS OF 20-YARD BANKS.

The purchasing of pillars of coal for the support of bridges, viaducts, tunnels, &c., always involves heavy outlay, and it is therefore necessary to determine the minimum size of pillar that may be used with safety. The foregoing rules will enable engineers to do this with comparative accuracy, in the absence of special local factors, which must be dealt with upon their merits, the pillar being altered to meet them. In the case of large pillars at a depth of more than, say, 300 yards, it is frequently found possible to rib them across, or to work half and leave half by means of banks about 20 yards wide driven through the pillar, as shown in *Fig. 5.* In this manner a considerable saving is effected in the purchase price. The strata appear to arch themselves over the worked portion, and there is practically no subsidence.

Where several workable seams of coal occur, one below the other, it is necessary to consider the cost of possible repairs, and probably of a new bridge, before going to the great expense of purchasing support in an increasing descending ratio in all beds. In most cases where the coal is more than, say, 300 yards deep, and where the superstructure of the bridge is of steel or of wrought iron, the coal may be extracted in a regular moving face and yet perhaps do little damage, save the lowering of the general level of, the line and its attendant inconveniences. The decision as to this, however, must be left to the discretion of the engineer, who will,

no doubt, have access to the colliery plan showing the workings approaching the statutory limit, and will be able to form an opinion accordingly, so far as that aspect of the pillar is concerned.

Suiting the Design to the Supposition that the Coal may afterwards be worked out.—Tunnels and aqueducts should have support, and therefore do not come within the scope of this section. In the case of bridges, to which it chiefly applies, the remarks previously made as to steel superstructure, and well-tied abutments and wings, are again applicable. The goaf should be packed as solid as possible when the coal is extracted. The subsidence that may be expected, amounting to about two-thirds of the thickness excavated, will, if necessary, have to be provided for in the first height of the bridge; as, for instance, if it be over a waterway where the water-level is maintained, by raising and puddling the banks as subsidence proceeds. Lofty viaducts should be protected by pillars; lower structures may be worked under as described. The girders should have a good bearing upon the piers, which should be solid and not pierced by an arch. Provision as to height is necessary as in the preceding paragraph, and the goaf should be tightly packed, as before.

The Paper is accompanied by a drawing, from which the Figures in the text have been prepared.

Discussion.

Mr. Mansergh. Mr. JAMES MANSERGH, Vice-President, was sure the members would agree that a vote of thanks be presented to the Author for his useful and practical Paper. Any engineer was to be commended, especially a young engineer, who gave to his fellows the benefit of such observations as the Author had made. The Paper dealt merely with subsidence due to coal-workings; but the members were all aware that subsidence took place in many other workings, especially in the district where brine was pumped. The discussion would therefore be open on the subject of subsidence not only from coal-workings but from brine-pumping, and any other operations of that nature.

Mr. Saner. Mr. J. A. SANER exhibited upon the screen a series of photographs illustrating the effects of subsidence due to brine pumping in the district of Northwich. The question of subsidence, as brought forward by the Author, was very interesting; and although, fortunately, he was not frequently called upon to design permanent works over such places as the photographs had illustrated, it was instructive to learn what was done in the coal districts and in other districts where such subsidences took place A rule was laid down by the Author for finding the area of subsidence caused by working the coal; but he was afraid that in Cheshire, in the Northwich district, such rules would be entirely useless. There, instead of having the coal seams 4 feet to 6 feet in thickness, there were two superimposed beds of rock-salt 84 feet and 82 feet in thickness, and a layer of marl about 30 feet thick between them. The effects that had been seen on the screen were caused by the fact that the salt was obtained in two ways. In one case the rock-salt was mined as in an ordinary mine, the workable portion being about 20 feet thick in each bed, so that the mines when left were about 20 feet high. The remainder of the salt-bearing strata was worked by pumping water which was converted into brine, either natural springs—although he was afraid they had now been eclipsed by the artificial springs—or water which had been allowed to run down into the mines, thus the pillars which supported the roof were eaten away, and the subsidence took place. He thought that in some places the ground had subsided to the extent of 60 feet or 70 feet, and

Mr. Saner.

he knew of much deeper holes in special cases. It was not known whether the subsidence had stopped, neither could the exact area or the exact extent of the possible damage be ascertained. Further, although plans of the old mines were kept to a certain extent, the water had done away with very much larger areas of the salt than were mined. It was impossible to predict where the subsidence would take place next. The terrible looking holes which had been shown on the screen occurred chiefly on the edge, somewhat beyond the edge, of what was known to be the extent of the rock-salt; and he thought in that case it bore out the Author's statement, that the greatest effects of the subsidence were not exactly over the rock or over the coal, but some distance outside the edge of the working. The subsidences in Castle Northwich and Leftwich were about 300 yards south of the rock as at present known; and it appeared as if the draw of the subsidence assumed an angle approximately equal to the angle of repose of the overlying strata, and that those holes might be caused by the overlying marls (because all the rock-salt lay in the Keuper marls) cracking, and the surface-water drawing down the sand and glacial drift into the caverns beneath, forming as it were an hour glass. He thought the cone-shaped cavity which was formed was merely filling a similar cavity below, and that the earth that fell from the cone was deposited in a heap in the cavern below. These conical cavities were sometimes as much as 120 feet in diameter at the surface. That appeared a feasible theory of the extraordinary subsidences which took place, not only in Castle Northwich and Leftwich, but also, as it were, in a ring round the known area of the rock salt. As to the buildings suitable for such places, he would prefer there were none at all; for his experience had shown that however solid masonry might be made, or whatever the work was on the top, it was more or less damaged by such subsidences. One of the bridges over the river Dane, a tributary of the Weaver, for instance, had masonry piers that were exceedingly solid so far as could be ascertained. They had been built for some years, but they were cracked down the centre in halves, not through the joints of the masonry, but straight down the middle. That bridge had, from ascertained figures, subsided to the extent of 7 feet since 1882, so that it could not be wondered that the masonry of the abutments was somewhat cracked. It appeared, so far as ordinary buildings were concerned, that the form of structure which seemed to be a survival of the fittest in Northwich was either wooden or iron framework filled

Mr. Saner. with stucco or brickwork. The house which had been shown on the screen on its beam end was built in that form, and it seemed very little damaged by being turned over through an angle of nearly 45°. If there had been a foundation upon which to rest hydraulic jacks, that house would never have been pulled to pieces as it had to be. In the subsidence which took place on the 15th November last, a house of similar construction moved bodily over into the street; the lower sills moved about 1 foot, and the upper sills overhung 4 feet. But within 48 hours the owner of the house had borrowed hydraulic jacks and had raised it into a horizontal position again. The Weaver Works, of which he had charge, with the exception of the town bridge at Northwich, which he was now engaged in removing, and replacing with a swing bridge of a special construction he hoped at some future date to explain to the Institution, had been entirely removed from the subsiding district, but up to 1859 the effect on the locks and the weirs was of a disastrous nature. He believed that either two or three locks had to be rebuilt within very short periods close to the town of Northwich. He had, however, raised one part of the towing path 12 feet in less than 10 years.

Mr. Wright. Mr. Tylden Wright remarked that the damages caused by salt subsidences were very great, but he was afraid they were beyond all rules, and would not be met by any mathematical formula. The matter was so serious with regard to the coal measures, that he was surprised the subject had not earlier been brought before the Institution. Last year more than 200,000,000 tons of coal were raised, and that represented almost 50,000 acres of coal of a thickness of 3 feet. According to the Author, with whose results he thoroughly agreed, the subsidence over that 50,000 acres would be no less than 2 feet. When that took place in a district permeated with canals and railways, it was a most serious matter for the proprietors of those railways and canals, for the engineers who advised them, and he might also add for the engineers who advised the owners of private mansions as to the effect of that subsidence. He agreed, in general, with the Author; and allowed that the depression would take place in the lines that the Author represented, that if the seams were horizontal, the line of fracture would be vertical; if it was inclined, most mining engineers would allow that it would be half-way between the angle of the seam at the surface and the surface itself. But he did not agree that the wave of subsidence followed the excavation of the coal. He had found from most careful experiments extending over 7 years, month by month, that the subsidence

began considerably in advance of the working of the coal. An instance he might refer to was Newstead Abbey in Nottinghamshire, one of the finest historical mansions in the country. It was his lot to advise the owner whether the pillar of coal that had been planned to protect it should be left, or whether the whole of the coal should be swept out by long-wall work. He found that the pillar required to protect it would be at least 40 acres in extent, and about £4,000 in value; and even if the pillar were left, then the lakes which were close to the Abbey would be thrown out of level, and a great deal of trouble would be caused. He therefore recommended that the pillar be entirely swept out by long-wall work. The workings were 560 yards from the surface, and the seam of coal was 3 feet thick, but the material removed was 3 feet 8 inches in thickness. Observations had been kept by Mr. Bagnold Smith, the managing director of the Newstead Colliery Company for 7 years. Fortunately they began before the coal was worked, and it was found that 9 months before the coal was excavated under any portion of the Abbey, it began to move and to fall at one end at the rate of $\frac{1}{8}$ inch per month. The face of the work was then 90 yards distant from the Abbey. As the work advanced the wave of depression increased from $\frac{1}{8}$ inch a month until it ultimately reached $1\frac{1}{4}$ inch per month, or a total depression of 15 inches in the year. At one time, a year or two ago, one end of the Abbey was 10 inches lower than the other. But to show how smoothly and steadily the fall took place, he might mention that in the west window of Newstead Abbey, which was one of the finest architectural possessions of the country, with the loose tracery of the window, which was there 800 years ago, not a single stone had dropped out, and it was all just as it was, although it had subsided no less than 23 inches. He cited that instance as, in his opinion, confirming the modern view, that the best plan to deal with such questions, where there was a deep seam and the strata were moderately favourable, was to sweep the whole seam out by long-wall work as rapidly as possible. There was no question that if the pillar had been left grinding would have been going on for years, the level of the lakes would have been disturbed, and it would be impossible to surmise the fate of the Abbey. The working face was now 500 yards past the Abbey, and although there was still movement of $\frac{1}{8}$ inch per month, practically it had come to a state of rest again. But matters had not always turned out in that way. He could name another house in the immediate neighbourhood—the house of a Mr. Wright.

Mr. Wright. noble Duke in Nottinghamshire—where, instead of depression taking place—the strata tilted up. One night, about 3 years ago, when the family were at dinner, the floor rose suddenly. The Duke's chair was raised 4 inches above the rest at the table and a good deal of alarm was felt; but, no other serious damage had been caused to that house, and he thought £100 would probably pay the whole extent of it. The coal had been swept out from the same depth and to the same thickness as in the case of Newstead Abbey. After that explanation he thought the Author would agree that the best course was, instead of leaving a pillar of 68 yards radius, amounting to about 3 acres of coal, as shown on the diagram, to have swept the coal out and taken the risks in the same way as he had in the case of Newstead Abbey. But all cases of colliery working were not of that nature. He had had many cases in his experience where, instead of the surface subsiding regularly, there had been apparently no sign of subsidence on the surface. He knew workings in the South of England where large areas had been swept out under a city without the slightest perceptible subsidence having taken place. The same thing had also occurred in Derbyshire. He attributed that to the fact that the strata immediately above the coal were much stronger than the strata below, and that when the weight was taken off the coal and the coal was excavated, the "floor," as it was called, being of a soft nature, rose and filled the excavation, or the goaf, and the rock above remained as it was, but the excavation was filled from the floor. That was clearly proved by having to "dint," as it was called, or take up, a portion of the floor to keep headway in the gate roads for the horses. It was further proved, because in driving roads through the old goaf years after it had been made, it was found that the floor of the seam, instead of being in the floor, where it would be expected, was really up where the roof should be. He agreed that general rules for the subject could not be laid down, but that only a certain angle of repose, or angle of rest, could be assumed, which the Author took at values which worked out very satisfactorily and safely. He considered the best method of dealing with ordinary cases of subsidence at considerable depths was to sweep out the whole of the coal as quickly as possible, at the rate of about 2½ yards per week, and pack the waste closely; then very little damage would result.

Mr. MacDonald. Mr. J. A. MacDonald took a great interest in the subject of the Paper, as he was responsible for many important structures on

Mr. MacDonald.

the surface in coal-mining districts. At the beginning of the Paper, the Author had alluded to the coal-fields in the West of England and Wales, and it was an interesting fact that in a city in the West of England the coal had been worked for a century and a half, and he believed probably longer, under parts of the city, without causing the slightest injury to any of the buildings. But he thought that was not altogether due to the band of rock that was left above the lower coal, but was quite as much, if not more, due to the fact that the coal was pitched up at a very high angle, the full dip being, he believed, 16 inches to 1 yard, and the sandstone rock, which was 40 yards or 50 yards thick, acted as a girder, and there was practically no settlement. He did not agree with the Author's view that structures of the arch form should be avoided if mining operations were proceeding beneath. Arched bridges of moderate spans behaved extremely well while coal-workings were passing underneath, assuming that the coal was of moderate thickness and at a reasonable depth, say 100 yards. He had had an instance within the last few years of an arched bridge carrying the main line of railway over a road. A face of coal-working was approaching the railway, the seam being about 7 feet 6 inches thick, and at a depth of only 72 yards. It was thought by the local engineer in charge of that part of the line that the bridge would probably be destroyed, and it was decided to take down the arch and erect an iron superstructure. The girders were delivered at the site, and the workings proceeded, but the arch showed no cracks. The workings came under the bridge and passed it, and the bridge still showed no signs of distress. The arch was still in a thoroughly good condition, and carried the main line of the railway, and the girders had been used elsewhere for another purpose. The span of the arch was about 20 feet. His remarks would not apply to large spans of 50 feet or 60 feet. The bridge was as good now for practical purposes as it ever was. Another case of a similar kind had occurred not very long ago; a bridge had been constructed in a district where there was coal-mining underneath, with a girder top and headways of 18 feet or 19 feet. The bridge began to settle, the abutments were cracking and moving together a little, and he decided to put in an arch. That bridge was now in a very satisfactory condition, the workings having passed under it. Nor did he agree that in all cases coal should be bought under tunnels; he thought that each case should be considered independently on its own merits. If the coal was swept out steadily, fairly, and regularly, tunnels

Mr. MacDonald. in certain conditions would take practically no harm; but if, as in the case the Author mentioned with regard to the strike, the workings were suddenly stopped and commenced again, more harm resulted. With regard to tunnels, an instance had occurred in his own experience of a 5-foot seam of coal which had been worked from underneath a tunnel for which he was responsible, at a depth of between 200 yards and 300 yards from the surface. That tunnel hardly had a crack in it and the traffic through it had never been delayed for a single moment. With regard to the question of buying ribs of coal for the protection of structures instead of solid pillars, he had no experience of that arrangement, but he had purchased coal for the support of viaducts by laying it out, on the plan of a chess-board, and buying all the black squares. That had been done a little while ago, and it had answered well, and the viaduct was now in a very satisfactory condition. The pillars should be of a fair size; in the case he had mentioned, he believed they were about 50 yards by 24 yards.

Mr. Inglis. Mr. J. C. INGLIS observed that the effect of working coal below a structure like a railway viaduct was sufficiently obvious to show that the chances were that serious damage would result. The first impression he had formed of the Paper was that the Author was somewhat bold to at once plunge into mathematics as to the area required to provide a support for the superincumbent structure. He had taken the trouble to test the Author's formula by one or two cases he had had to deal with lately, and, rather against his pre-supposed idea, the result came out fairly correct. At any rate, he thought he might take it, as one of the speakers had said, that the formula represented a practice which was fairly general on the part of mining engineers. There was only one point which occurred to him, and it was one involved in an important case he had under consideration at the present time, viz., dealing with subsidence on coal measures having a somewhat high angle. Taking *Fig. 4* as an example, in the case he was thinking of, a tunnel, he should not have quite gone to the length shown in the *Fig.*; he should have been inclined to take the coal which was to be purchased further down the slope towards the point F′, because he had a lively terror of the effects of "pull." The allowance of support suggested by the Author on the low side of the coal measure would hardly be enough, in the case of a high angle. The formula proposed was merely an expression of practice generally followed, but he would not purchase a piece of coal so much on the high side of the

structure to be supported where the angle of the coal measures was high. A slight idea of the general effects which coal-mining had on railways could be obtained from the fact that in one district the Great Western Railway had annually to provide and to replace something between 60,000 yards and 70,000 yards of filling to make good the subsidence which took place from coal-mining. Cases had been known—he thought one was mentioned in another part of the country—of a canal having been raised. There was a canal in South Staffordshire which had been raised 20 feet. In the same district his company had several goods yards which had been raised quite that height, and many other extraordinary lifts, including bridges. The evidence, as far as bridges were concerned, was that the honours were equally divided between arches, as to their good behaviour and their bad. The Great Western Railway had arches which had behaved nobly under very distressing circumstances, and they had others which, so to speak, had thrown up the sponge on the first indication of distress. It was very difficult to predicate much upon the subject in a general way. He had also had experience in another exceptional case, namely in the West of England, where the railway company owned the minerals below their property, and within the last 9 months a considerable area of those had been sold to be worked out; but the coal in that area was overlaid by very thick strata of sound hard rock. It was not anticipated that no settlement would take place; but when there was a large area of solid rock over a coal seam the settlement could be foretold exactly, and it would be uniform within the large limits. It depended upon the amount of packing and the pillars left; but one point was becoming apparent, that, while pillars were of advantage for a time, there was a slow process of disintegration, which occurred year after year, after it was thought the whole settlement had been remedied. He could point to a case involving a large sum of money, where a company, thinking to avoid the large expenditure of buying the whole of the coal, compromised the matter by providing for what was believed to be a safe area of support by pillars. The consequence had been that the maintenance works had been completed apparently after the first settlement took place; but a slow settlement occurred and was found to be much more troublesome to deal with than the first. With regard to the process of gradual subsidence of the ground due to working under the Merthyr tunnel, of which he knew less than Mr. Lloyd, Mr. Inglis.

Mr. Inglis. one of the divisional engineers, it was a tunnel about 1½ mile in length, and as the workings progressed the settlement in the tunnel took place. He could not now tell the relative position of the workings and the settlement, but at any rate it took place in waves and progressed from one end. of the tunnel to the other, except at points where wide faults occurred. The greatest difficulty arose from the fact that while the rest of the tunnel settled—the total settlement had been about 10 feet—the portion over the faults did not settle and had to be cut down and lowered so as to make it join with the lower portion which was due to the settlement arising from the working of the coal. He should have liked to have seen the data, as an Appendix to the Paper, on which the Author's formula was built. It might have the effect of stimulating other members to add to it. The only value the proposed formula had was the practical area it covered in the way of examples which were found to be more or less efficient, coupled with the circumstances of each case. The sums involved were so large that it was to railway companies' and canal companies' interests to watch each case and deal with it on its merits. He did not know whether it was asking too much of the Author, but the formula was stated to be founded on certain definite cases, and it would be worthy of the volumes of the Institution if those cases were given.

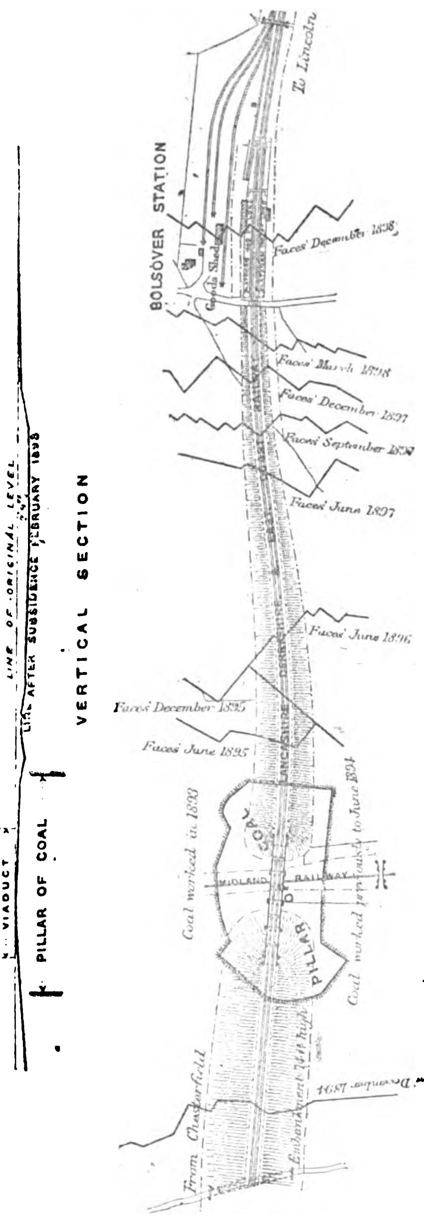
Mr. Cooper. Mr. R. Elliott Cooper remarked that his own experience of the effects of subsidence caused by coal workings had now extended continuously over about 6 years. In 1892 a main line of railway with a number of branches had been commenced through a district that had not been worked except in a slight degree. This was a coalfield about 150 square miles in extent, a large part of which was now being worked, and the effect of the subsidence could be seen, he might almost say, from day to day. When the railway was first laid out, the Chairman of the Company, who was himself a large colliery owner and an eminent engineer and a member of the Institution, expressed his opinion that it was a mistake to buy any coal at all; and that view entirely agreed with Mr. Wright's opinion, who had given that very good advice. With the exception of a single case the opinion of the Chairman was followed; and although several out of fifty or sixty bridges on the railway which would be undermined, only in one or two cases had there been slight signs of damage caused by the subsidence, and practically speaking no injury whatever had resulted; whereas if any attempt had been made to buy the coal and so protect the works, the amount of money that would have been so expended would have

Mr. Cooper.

greatly exceeded what it would have cost to even rebuild some of the bridges. The amount that was being asked in the Derbyshire district for each of the several seams of coal for the purpose of pillars was so great that it became a matter of serious consideration as to what extent, even in the one case where a pillar was bought, it should be done. That single case was a viaduct 80 feet high from the foundations to the rail level, and if he had known then as much as he did now, if he had been able to foresee how very little damage the subsidence created, he would certainly have recommended that even in that particular instance the coal should not have been bought. There was a point that perhaps was not sufficiently considered even apart from the question of the safety of the structures. Supposing, for instance, a number of detached pillars of coal were bought, in a district like that he had mentioned—where no coal had been worked and where in years to come the whole of the surface subsided to an entirely new level varying between 1 foot and 3 feet 6 inches—if detached pillars of coal were left, or a number of fixed points were created, which might be very inconvenient. For instance, if there was a viaduct or tunnel immediately adjoining a station, and the level of those two points was fixed, and the coal was not bought under the station, a gradient of considerable steepness would be formed between the two points. The station could not be raised, unless it was pulled down and the sidings ballasted up, and the result would be a very awkward position, which might have been altogether avoided. He had taken great interest in watching the effect of the subsidences, and he had found that any little damage that was done was almost invariably caused by the "pull" rather than by the subsidence itself. He had observed in one case that whereas a parapet of a bridge had slightly opened, caused by the pull, when the bridge had become undermined completely the cracks had been entirely closed, because the surface had returned to its level instead of being, as it were, on a curve. That had occurred not only in the case of one of his bridges, but in the offices of the colliery company itself, where a crack appeared from top to bottom; but now that the whole of the coal had been cleared away from under the building there was not a crack to be seen. Another point that had to be considered in all questions of subsidence was the strata that overlay the coal. In the particular line that he referred to for about 12 miles the strata immediately below the surface, for a great depth was a strong blue bind, but in another district on the same railway there was about 50 feet or 60 feet of solid limestone. The difference between the effect of the

Mr. Cooper.

Fig. 6.



Horizontal scale, 1 inch = 8 chains; Vertical scale, 1 inch = 40 feet.

LANCASHIRE, DERBYSHIRE AND EAST COAST RAILWAY, COAL-WORKINGS AND SUBSIDENCE.

subsidence on those two portions of the line was very remarkable. Where the blue bind existed there was invariably a considerable "pull," the effect was quite noticeable. Where the limestone was found there was no effect whatever of the "pull." There it simply went as if the surface were a piece of india-rubber. At one place he had in his mind where there was a long piece of level line perfectly straight, it could be seen year after year how a slight curve was formed, but without the slightest injury to any single structure. As the subsidence proceeded, the level piece of line would eventually take its original form, but it would be about 18 inches lower. The mines in both cases were between 400 yards and 600 yards deep. Where the

limestone came to the surface, and, as he had said, was about 60 feet thick, the subsidence at the most that he had been able to find was only between 1 foot and 18 inches. At the adjoining colliery, and with the same depth to the coal, but where the blue bind was the overlying strata, it had amounted to between 2 feet 6 inches and 3 feet 6 inches. The effect of subsidence amounted to practically nothing, but the "pull" undoubtedly had a slight effect. One seam was 5 feet thick and the other 5 feet 6 inches thick. Several speakers had referred to the probability that even where a supporting pillar of coal had been left slight subsidences will follow when the coal round the pillar had been taken out, and he could corroborate this fact from instances within his own knowledge. He had a station where the coal was being worked along the line of the railway, the face being at right angles. When the workings reached a point about 60 yards from the end of the platform there was not the least subsidence but a distinct "pull," and the gas-pipe running under the coping of the platform broke. At the present time there were three or four small cracks of about ½ inch; but now that the workings were under the station apparently the "pull" had entirely ceased, and the platform was gradually settling to its final level. All the experiences that he had had, and they entirely agreed with what Mr. MacDonald and Mr. Wright had said, pointed to the fact that engineers need not be very much afraid of building structures and allowing the coal to be worked out underneath, at any rate if the depth was anything like 400 yards. As to the question of the relative advantages of arches and girders, he did not think there was much difference. He was not speaking of large arches, but small bridges, such as occupation bridges under deep embankments, where it would be foolish to carry up abutments to carry the railway by a steel superstructure merely to avoid running the risk of any possible damage to a small bridge. On the railway under his charge he had a great many small-arch bridges, and in no single case had the least damage occurred. Mr. Cooper.

Mr. H. S. Childe desired to suggest that there was an element which the Author had probably not considered in laying out the size of a pillar, namely the nature of the coal that was to give the support. Some of the coals—he referred to Yorkshire and North Derbyshire—were hard, and the pillar to be left would not be so large as the pillar of some of the softer coals, and it might be that the Author's rule would not apply in that case. With regard to *Fig. 1*, there was another cause of damage sometimes to buildings on the surface when the coal was worked from the Mr. Childe.

Mr. Childe. inner angle of the fault. There were cases where to support a building coal must be left under the fault to the extent of about 220 yards from the foot of the fault. The lie of that fault was probably an average Yorkshire one, about $2\frac{3}{4}$ to 1, or an angle from the vertical of 20°. With regard to the other cases the Author had brought forward in the *Figs.*, he thought that, generally, the members would agree with the Author, excepting that probably he had not considered the question of the line of subsidence going into the solid. His line of subsidence went goaf-ward only, but there were cases when it went into the solid to the extent of 12° to 17° from the vertical, and that required a great deal of watching. If the formula was meant to apply where the whole of the coal was to be left, the question arose when the owner, who was leaving coal, was to be compensated, whether he should not also be paid for consequential damage or extra cost of working. It might be that it would be more economical and better to go further and buy the whole pillar. The attrition and decrepitation set up in some seams in those pillars were in progress from month to month, and it would be better to buy a solid pillar than buy in what was sometimes called gridiron fashion. Then the structure that was to be supported had to be taken into account. It might be that there were only some light buildings, but if there was almost a village, the question of a pillar or no pillar would have to be considered very carefully, and if a pillar, it would have to be a very large one. The other question that had to be considered very often was where water had to be supported. In supporting railways or buildings there was no fear of damage to the mine. The surface might or might not be damaged. But if it was a reservoir bank or a canal, it sometimes had to be considered whether, although the working of the coal might not do very much damage to the canal, it might not cause fissures in addition to subsidence, and there might be a claim in respect of damage by the water flowing into the mine.

Mr. Ross. Mr. A. Ross observed that in devising a new railway scheme over an undeveloped field of coal or a field that had probably not been proved, engineers had not very much guide, and it should be recollected that a good number of the railways in England were so constructed. But if an engineer had knowledge that he was on a coal-field, and had probably the mining engineer's report, it was only due to the work that he should take certain precautions. Whether he should avoid tunnels and viaducts was another matter. The physical conditions of the coal-fields of England did not admit of avoiding them altogether, but certain

precautions ought to be taken. No doubt the tunnels, for instance, ought to have inverts, and the foundations ought to be perhaps better than usual. As for the viaducts, he did not suppose arches could be dispensed with. He was not so afraid of arches as had been anticipated; but there was no doubt that in single bridges a metallic superstructure had great advantages. It had been his practice for many years to divide those superstructures so that each line of rails was self-contained. The great advantage of that was that when subsidence had taken place and the railway had to be lifted, one line could be lifted at a time, and the other could remain in use. With regard to arches, in many cases of his own he had to pull down an arch, especially an arch over a railway. If there was only limited headway to start with, and there was subsidence at all, and the line was kept up, the arch came within the gauge and the rolling-stock would come into contact with it. Generally for that reason alone overlying arches had to be pulled down when there was serious subsidence. But, after all, it was largely a matter of degree. The case that the Author had referred to, was that of a subsidence caused by one seam only, but in most of the coal-fields—and in some more than others—settlements had scarcely taken place from the subsidence caused by one seam, when other seams were taken out, so that the subsidence due to coal working might extend not only over 5 years, but even over 20 years; and he had known in his own experience many cases of that kind in which the extent of subsidence had been very great. In the case of buildings, the precautions necessary and obvious were to provide framed buildings at the stations, when the lifting would be much easier, and the damage would be much less. As was well known, an existing railway company, before the working commenced, received due notice of the intended coal-getting under the Clauses Act, 1845, and they had 30 days to consider what was the best course. The mining engineer usually made his report to the engineer responsible for the safety of the works, and he decided whether to recommend purchase or not. He was not much in favour of purchasing unless he was actually compelled to do so. There were cases where, for the safety of the line, it was obvious that coal purchases must be made, and in the case of several seams of coal lying underneath tunnels and viaducts, sooner or later purchase would become necessary. He had found, from many years' experience, that the mining engineers' reports told with very great accuracy what was going to occur; but with coal-mining, although not quite so much perhaps as with other Mr. Ross.

Mr. Ross. mining, the unexpected did happen. There was the pull and the draw, and in many cases the pumps working in a wet mine drew quicksand for long distances, and the effects were felt at such long distances that it was even doubtful which mine was causing it. Therefore he thought it was obvious that a definite procedure could not be stated that would help in deciding, under all circumstances, when not to purchase the coal. The whole disturbance has to be carefully watched and dealt with according to the effects.

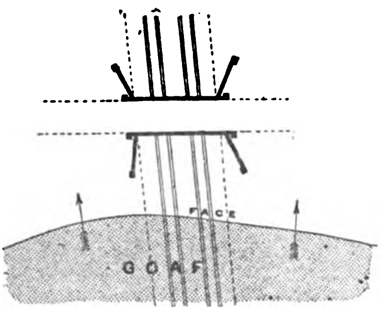
Mr. Worthington. Mr. W. B. WORTHINGTON desired to add a few remarks as to the relative qualities of the arch and the girder bridge. He did not go quite so far as Mr. MacDonald, but inclined towards the view expressed by the Author. He had never had to take down a girder bridge from this cause, yet he had had to take down several arches, owing to their failing through coal subsidence. With regard to the point named by Mr. Ross, namely, the superiority of the girder bridge to the arched bridge over a railway, if 5 feet of coal was worked underneath a girder bridge, and it subsided 3 feet 4 inches or so, the girders could be lifted easily without interfering with the traffic on the railway, but if the bridge over the railway was a stone or brick arch, unless it was abnormally high to start with, it was necessary either to let the railway stay at the level to which it had subsided or pull the arch down. That was a very important point with lines which were so crowded with traffic as the railways which passed through coal districts. With regard to the pillar to be left for the support of structures, he had had an opportunity of observing the effect of leaving pillars; and he thought there was no doubt that greater damage was caused to the structure on the surface from leaving a pillar which was too small than from the entire taking out of the coal. If the pillar was too small the pull at the structure on the surface from all sides was such that it was very seriously damaged. With regard to the gridiron pillars it happened that within the last few months he had met with a case which threw a little light upon that subject. In a railway which was made 48 years ago the line was made above a bed of coal which had been worked on the pillar-and-stall system, rather more than half the coal having been got, and the spaces were partly filled in with rubbish. The seam was near the surface—in fact, running out of the surface at one point and gradually getting deeper and deeper. At a point where it was about 5 yards deep a subsidence had occurred within the last few months, the top crowning in. That appeared to show that the pillars and roof had decrepitated

during the 48 years. They had carried the weight up to the end of 48 years. Mr. Worthington.

Mr. W. WALTER ROWLEY exhibited upon the screen four photographs illustrating the effect of subsidence of about 4 feet upon the banks of a canal, under which two seams of coal amounting to 7 feet 6 inches in thickness had been extracted, at a depth of about 200 yards. When he had first, many years ago, to consider and apply experience previously gained in mining operations to the working of minerals under, and the support of, railways, canals, reservoirs and other engineering works, he thought the task would be easy if the rules governing the size of a pillar to support a building could be reduced to a formula. But the longer his experience the more he was impressed with the difficulty of arriving at such a satisfactory issue. He found in practice the laws of theory could be used only to a certain extent in framing a general rule, which had to be modified according to the circumstances and surroundings of each case. According to a rule sometimes recognised, the pillars should extend on all sides to a distance equal to one-tenth of the depth of the seam plus 20 yards. Such a case as that given by the Author, namely, 400 yards deep, would give a fringe of 60 yards. This rule is applicable, as an approximate basis, to horizontal mines in which the thickness of the seam did not exceed 6 feet. In theory the circular pillar was correct, but in practice it was not found so desirable; often a square, rectangular, or still more irregular shape, had to be adopted in order to meet the special necessities of the case. One of the first points to be considered was the amount of subsidence that could be expected, because if that was small, the question of support might possibly be dispensed with. Such a question was affected by packing and other considerations. In considering the extent of support, the compensation to be paid to the mine-owner was often considered a very serious item to deal with, but he had sometimes found it difficult when advising that no pillar be purchased, to justify throwing on the engineering department such a grave responsibility as rested with them in maintaining the permanent way. From his record of over six hundred cases he had dealt with he found that less than 10 per cent. had had pillars purchased for their support. Protection for the railway by a pillar was never sought for unless the gravest sense of economy, safety and convenience, rendered it necessary. In working coal under bridges the method to be employed had to be taken very carefully into consideration. The advantage of the face of coal workings approaching a bridge broadside was shown in *Fig. 7*. If coal could be worked rapidly in this Mr. Rowley.

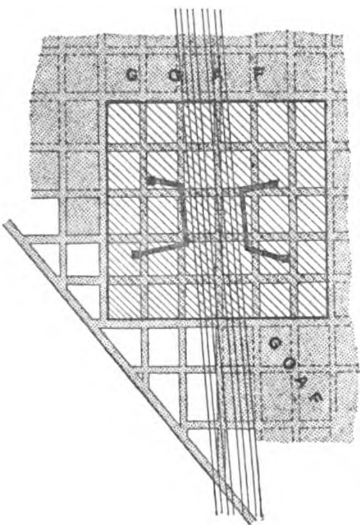
Mr. Rowley. manner the minimum amount of damage would take place; but if the bridge was approached end-ways, the girders were found to yield and the buttresses gave way; and if there was any stoppage in the operations of the mine, the effect upon the bridge was far more serious. In *Fig. 8* was illustrated the first principle of support, namely, as far as possible to utilize the existing workings of a mine when worked on the pillar-and-stall system, so as to provide, with little interference to the mine—which meant the minimum of cost to the railway—an adequate support. An adaptation of the existing blocks or pillars of coal was also illustrated in *Fig. 9*, dispensing to a great extent with the important question of severance by simply recognizing the existing pieces of coal, and ordering them to be left in such a position as would best serve and protect the property. It had been mentioned by Mr. Elliot Cooper that in a line in which he was concerned no pillar had been purchased for the protection of the works, except in one case. That line ran from west to east, beginning at Chesterfield and extending to Lincoln. A few miles distant from Chesterfield it left the exposed coal measures, which had an eastwardly dip under the Permian rocks and New Red Sandstone, and gradually assumed a great depth, rendering the difficulties of subsidence comparatively slight. The coal-field was not yet opened up under the greater portion of the line, and in the only case where

Fig. 7.



LONG-WALL FACE APPROACHING A BRIDGE BROADSIDE.

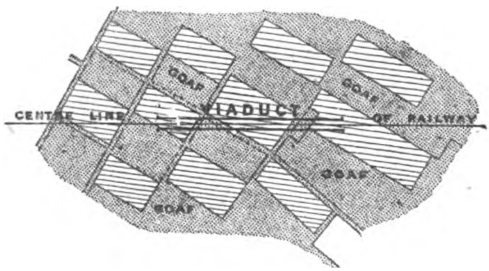
Fig. 8.



SUPPORT FOR A BRIDGE IN PILLAR AND STALL.

there was any necessity for the serious consideration of the effects of subsidence, namely, an important viaduct, support was purchased. The case of this railway was very different to the old mineral lines which had a very great mileage in the heart of the exposed coal-fields, with minerals varying between 2 feet and 30 feet in thickness, being worked at all depths. Modern railways had the advantage of experience, obtained at great cost by the older systems with regard to the difficulties of subsidence, and in some cases circumstances might enable them to so construct the works as to allow of a moderate subsidence. In his experience of the older lines which were made before the extending character of the coal-fields was properly understood, there had been such a limited margin in the height of some bridges that the rails had had to be lowered—a process which could only be carried on to a very limited extent, and in the end sometimes requiring the bridge to be rebuilt. He would only add that in judging of such an important matter it was desirable not to base conclusions on exceptional cases, for proper study of such a subject could only be carefully undertaken from the consideration of many cases distributed over a wide area of observation. Mr. Rowley.

Fig. 9.



PILLARS LEFT FOR VIADUCT IN ORDINARY COURSE OF WORKING.

Mr. R. J. GIFFORD READ remarked that the subject of the Paper had come under his notice in the case of bridges he had been concerned with in South Wales. A short time ago he had been employed by the Council of the Rhondda Valley to design the steel-work of some bridges that they were reconstructing over the River Rhondda. He had laid on the table two photographs of the old stone-arch bridges, which had been taken down. One of those bridges was a single-arch and the other a double-arch bridge—the arches being built of brickwork and the outsides faced with stone. Rhondda Valley was well known for its coal-workings, and the bridges were in the very middle of the district where the coal strike had occurred a short time ago. The bridges had been built 30 or 40 years, but settlements were first noticed about 8 or 9 years ago, and then they Mr. Read.

Mr. Read. seemed to stop and nothing further was thought of it until about 2 years ago, when the bridges commenced settling again. In the one-arch bridge the crown seemed to rise and the haunch on one side sank, and cracks appeared at various places; the arch stones in many cases appeared to be suffering such compression that they were splintered and cracked. In the two-arch bridge there seemed to be a tendency of the arches to slide one way on the abutment, pulling the arches over the centre pier, which then cracked. The cracks were not shown well on the photographs, as the latter were not intended to illustrate the Paper, but were simply taken with a view of preserving a memento of the old bridges. The bridges continued to move so much that the Council determined to take them down, and they had been taken down and the new bridges erected on stone abutments with steel girders. The bridges were only just finished. The cause of the settlement of the bridges apparently was the working of the upper seams of coal in or near them. Those seams were about 3 feet 6 inches thick and about 60 yards below the surface. The first settlement was probably occasioned by these workings, and then the bridges remained stationary for some years until the lower workings came into operation at a much greater depth, about 200 or 300 yards. It was supposed that the latter settlements were caused by the lower workings, combined with the effects of the upper workings. A little further down the valley from where the bridges were situated, he was informed that the Council, 7 years or 8 years ago, had built a new stone-arch bridge over the same river, which had remained there for 4 years or 5 years, and then suddenly had given way; so that they had to take the arch down and build the abutments higher and throw girders across; and those abutments had remained without any apparent settlement or trouble until the present time. That was an example of the effects of coal subsidence in that particular part of the country, where the coal was worked to an enormous extent in all directions. The strata above the coal was mostly rock, with seams of shale and fire-clay, and the bridges were founded on the rock. While on the subject of settlements he might perhaps be allowed to call attention to settlements in another direction entirely. On the last occasion the members were shown the effect of subsidences in the salt district of Cheshire. He had noticed during the past 2 years, and especially during the last autumn, the enormous effect produced by

the subsidence or contraction of the London clay, due to the dry summer. He believed that hundreds of houses had settled in various directions and had been cracked in many ways, in the district in which he lived, in the west of London. He did not understand the action of that subsidence, but it seemed that clay, owing to the dryness, contracted in a regular way, forming large masses of a crystalline form, such as was seen in the pillars at the Giant's Causeway, and the cracks went sufficiently deep to affect the foundations of houses, which were generally built 18 inches to 2 feet 6 inches below the surface. But recently the builders were sinking them 5 and 6 feet deep on purpose, as they said, to be out of the influence of the drought. Mr. Read.

Sir BENJAMIN BAKER, K.C.M.G., Past-President, had noticed that several speakers had touched upon the advantage of pushing on as rapidly as possible with work of an undermining character, which must necessarily be more or less of a trial to surrounding land and buildings. Speaking after an experience of the construction of from 20 miles to 30 miles of tunnelling of various kinds, he fully endorsed that opinion. He had been struck with the practical application of the principle many years ago in Chicago when carrying out the Lake tunnels. It was well known that the soil in Chicago was for about 200 feet to 300 feet deep little but mud. The American contractors were driving the tunnels, about 8 feet or 9 feet in diameter, lined with brick, straight ahead, under buildings, through that bad ground, and they had no hydraulic shields and no iron-lined tunnels in those days. But the vigour with which the work was being carried on was astounding. The men worked so hard that they could only keep at it for 10 minutes at a time, and then they stood aside, utterly exhausted, stripped to the waist and dripping with sweat, and gave up their picks and shovels to other men, who attacked the face as if they were charging a battery of Maxim guns. Working through that soft clay there was no attempt at timbering in the English sense of the word, but the brickwork was rushed in as fast as the mud was got out. Owing to no time being given for the soft clay to flow, the work was carried through the bad ground with practically very little settlement. Engineers who were accustomed to drive tunnels knew, of course, that some of the greatest damage arose from carrying timbered headings the whole length of the tunnel and leaving them standing a long time, because that gave the ground time for the slow flow, which took place in almost every kind of Sir Benjamin Baker.

Sir Benjamin Baker. soil that constituted the crust of the earth. An illustration of that slow flow was found in asphalt. If a piece of asphalt was cast in a mould, such as was used for Portland-cement test-pieces, and was broken in the same way that a specimen of Portland cement was broken, a sharp fracture would be obtained practically without elongation and with a tensile strength of 300 lbs. or 400 lbs. per square inch. But if a weight of 5 lbs. or 10 lbs. were put on that test-piece of asphalt and left, it would be found that in the course of a certain number of days it would break all the same; that a slow steady drag on the asphalt would effect a rupture with the mere infinitesimal fraction of the weight which would be necessary if the fracture were conducted quickly. He thought most engineers would agree with him that there was very much the same experience in tunnelling. If the work was pushed ahead as fast as possible and the ground was not given time to settle, there would be considerable self-contained arch and girder strength in the soil and nothing like the settlement which would be obtained were the work proceeded with very slowly and deliberately, although, on the basis of a false theory, it might appear to be a more secure and elaborate way of doing the work. It had been mentioned more than once during the discussion that the settlement of the ground surface did not nearly correspond with the amount of solid excavated underneath. It was also known in practical experience that ground which had been once disturbed, or buildings which had been once cracked, yielded much more readily than they did if they were intact, when mining operations were being carried on near them. The reason that the ground did not settle to the full extent of the excavations taken out was the fact, no doubt, that the virgin undisturbed soil was occupying the smallest bulk it possibly could, and that any disturbance of that ground would make it occupy a larger bulk, owing to the increased size of the interstices. That was seen in walking along the sea-shore, near the edge of the water, when the sand was just slightly glistening with moisture. In walking along and treading on the sand it would be noticed that the sand dried all round the foot. Instead of water squeezing out it disappeared like a flash, and the sand was dry all round the foot. The reason of that was that when pressed by the foot, the sand, which previously was in the smallest bulk it could occupy, was disturbed and made to occupy a larger bulk, and therefore the interstices formed, which constituted more or less of a vacuum, sucked up the water at once. In attacking virgin soil, gravel, sand, or anything of that sort, a little

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settlement might be caused all round the timbering in driving a tunnel, but the sand readjusted itself and occupied a larger bulk, and therefore the surface did not settle so much as might have been calculated. It might be said that such disturbed and open sand would not carry weight, but it would. A long time ago he had made experiments on that point by taking a long vertical column of sand in a square box, about 20 feet high and 2 feet square. He filled the box lightly with sand, loaded it with 20 tons to the square foot, which was carried without the slightest settlement. Then he hammered away at the load on top to imitate the vibration of a girder carrying a railway train, and no settlement whatever resulted. The sand with open interstices carried 20 tons to the square foot perfectly. He did not put on more; not because the sand would not carry it, but because there was no necessity for his doing so. Then he removed the load and gave the box three taps with a hand-hammer, and the surface sank 2 feet, showing that the sand was in the open and disturbed condition it might be in when driving a heading or tunnel, and yet it was perfectly competent to carry 20 tons to the square foot. That was the reason why in tunnelling through virgin ground and near to buildings which had not been previously cracked, as much damage was not done as where the ground had been already disturbed, or where the buildings had been cracked. In the latter case soil was being dealt with which would not afford any more interstices to compensate for abstraction of solids, and, in the other, soil was being dealt with that had been deposited by water into the smallest bulk that it would occupy and could afford interstices. In cases of settlement, as in many other cases, he thought models might be used by engineers more than they had been as a means of investigation. It was known what invaluable experiences had been gained from models of ships; that if a model of a ship was pulled along a canal with a velocity proportionate to the size of the model, then not only was the resistance obtained, but the actual forms of the waves which were originated by that body were of the same character as they would be in a full-sized ship. It was known also that if a model of a tidal estuary was made, and the water was allowed artificially to flow up and down—say a model the size of a large table—sandbanks would be produced such as Nature had produced herself in the estuary. Similarly in the case of settlements from tunnelling operations. A number of years ago, before the Blackwall Tunnel was thought of, he had to consider, for the Metropolitan Board of Works, the question of

Sir Benjamin Baker. the construction of a Thames tunnel, and in considering the form of shield which was to be used, he made use of a model. The model constituted, in effect, a square box with a glass side, the glass side representing as a picture the soil and the shield in the same way as a longitudinal section of a drawing would. The soil he made of alternating layers of dry peas and hemp seed, so as to get horizontal strata of ground, and then he drove the shield from one end to see exactly what flow of ground took place, as indicated by the altered positions of the coloured layers of seed. On the glass side of the box a picture was presented of which it was possible to take a photograph. Subsequently, some 8 years or 10 years afterwards, he found that the same thing was being done in a more perfect way by a French or Belgian engineer in connection with the pressure of earth on retaining walls, and the displacement of earth which occurred when the wall slid slightly forward or tipped over a little way. In that case the investigator used some very mobile sand in coloured layers, and fixed it after movement by pouring in isinglass or something of that nature into the sand, when the latter could be taken out as a solid. These model blocks exhibited every possible movement of a retaining-wall, and could be kept in a museum for reference. He thought, in many cases of settlement, there might really be obtained very useful information by reproducing the conditions on a small scale in a model with a glass side to the box.

Mr. Kay. Mr. S. R. KAY, in reply, said that in the preparation of the Paper he had endeavoured to adhere to general conclusions as far as possible, single instances being misleading. The formulas he had given were, he believed, those which an engineer might safely adopt as a basis in estimating and advising upon the support necessary to be left. No doubt, in the case of deep mines, more damage was to be apprehended from the pull than from the subsidence, but this was only the case in the absence of faults, otherwise the risk would be fairly divided. He considered it difficult to imagine subsidence taking place over solid ground; the sinking described as taking place so far in advance of the working face was due rather to the stretching of the more or less elastic strata consequent on the pull than to actual subsidence. Where deeper mines were being worked below one or more seams worked previously, and in which pillars had been left, the working of the low seam was liable to cause more damage to the surface than when such superior workings did not exist. The risk was accentuated, and both pull and subsidence might be looked for around the edges of the old pillars, and if these had been rather

small in the first place, so much greater the risk. Mr. Read's observations with regard to the two bridges corroborated his statement, the arches acting as might be expected when their equilibrium wer edestroyed. With deep seams, and in the absence of faults and superior workings, it was possible for the coal to be rapidly worked out without inflicting more damage than might be almost negatived after the subsidence wave had passed, when the surface resumed its former contour, and the original conditions were restored. There were, however, certain risks connected with it, the chief one being a stoppage of work from some unforeseen cause, such as a strike or an accident, when the pull would be intensified, and any damage probably rendered permanent. It had been remarked by Mr. Inglis and others that isolated pillars left for support became eventually crushed and broken by the weight of the overlying strata. He had no doubt this was the case in the deeper mines, except with very large pillars. The resistance of coal to a crushing force was comparatively low, and consequently, when the strata finally settled, the coal became crushed in a greater or less degree, according to its strength, and therefore a larger pillar was necessary for a soft coal than for a hard one. The crushing of the pillar, however, did not mean that it then failed in its power to support, as the coal could only be crushed into a space vacant to receive it. Generally the goaf was either packed or fell tight around the pillar, and the coal had no power of spreading under the pressure. Thus, although the coal might be crushed, it still might occupy almost the same space as when solid, and therefore had nearly the same sustaining power, the surface slightly sinking in proportion to the new form the pillar had assumed. With a more open goaf around it, as in the case of a rock roof and hard floor, the crushing of the pillar would cause it to spread rather more, and the surface would subside in a greater ratio than under the former conditions. The movement due to crushing was, however, very slow, and sometimes long delayed, so as to be seldom felt at the surface. He had no experience of damage actually resulting from that cause, although that such sometimes did occur he gathered from the experience of Mr. Inglis and Mr. Worthington. In the case cited by the latter, however, it might be caused by the old goaf caving in, rather than from the pillars decrepitating. In cases where the coal and roof were hard and the floor soft, the pillars were forced down into it by the weight above, and subsidence took place in spite of the pillars. The curious subsidence following the working of the coal under the railway Mr. Kay.

Mr. Kay. described by Mr. Cooper, where more pull over and more subsidence were noticed where bind was at the surface than in limestone, might, he thought, be explained by the unconformability of the Permian limestone to the coal measures. That would act like a fault and intercept the effects of pull and vary those of subsidence. The harder limestone, having strong lateral support, would naturally take considerably longer to subside than the coal-measure binds and shales. He regretted he could not follow Mr. MacDonald in preferring even small arch spans to steel superstructures above coal-workings; he preferred the methods adopted by Mr. Ross and Mr. Worthington. The stability of the arch depended entirely upon the rigidity of the abutments, and if either abutment subsided the equilibrium of the arch was destroyed and it became unsafe, and repairs or rebuilding might cause a cheap bridge to be a very costly one in the long run. The same remarks applied to the support of tunnels, even if inverted. He thought, in most cases, it would be less expensive to purchase support than to incur the expense and risk that damage from subsidence occasioned. Tunnel repairs were always costly; the possible repair of the tunnel from end to end might exceed its original cost, and very much exceed the value of the coal required for its support. He gathered that Mr. McDonald favoured working the coal from beneath the short tunnel he mentioned, and if it were the tunnel that his company were now opening out he agreed with him in not electing to purchase support, but not otherwise in the absence of any special facts bearing upon the case. He generally agreed with Mr. Rowley's remarks. No doubt, in cases of deep mines, the purchase of support would be a very large item indeed if it were decided to buy the coal, because large pillars were necessary, but he thought the grid-iron or the draught-board plan of buying pillars was a very good one, although Mr. Childe seemed to think that the former method would be almost as expensive as buying a solid block of coal. He differed from him in that respect, because from his experience the saving effected in allowing say one half the pillar to be worked was considerably greater than the consequential damage from the extra cost of working. It had been said that he was rather bold in deducing a formula for that class of subsidence; but, as far as his experience went he had failed to find a formula for subsidence resulting from coal-mining operations, and in that case it was difficult for an engineer approaching the subject to have any idea of what reasonable amount of support was necessary if he had had no previous experience on the subject. His view with regard to

that formula was to present something which would be a reasonable guide to an engineer who had not had perhaps much experience on the subject; but, whether he had or had not, it would be a means towards forming an opinion as to the quantity of support which he should buy. If he decided to do so the formula gave, he thought, a fairly correct minimum pillar. In special circumstances it would have to be enlarged, and there were considerations allied to each separate case which would have to be considered individually, and the pillar decided upon accordingly. Sir Benjamin Baker's proposal with regard to models was, no doubt, an excellent one with regard to homogeneous masses of strata, or where the strata were fairly uniform one above the other; but, with regard to deep workings in coal mines, he hardly thought that such a method could be adopted. In the first place, the strata were of a very varied character, hard and soft and medium strata following upon one another without any regularity, with sometimes thick rocks and sometimes thick soft shales; and in the second, the strata themselves were so broken up by the natural processes that had taken place since they were deposited that it was difficult to reproduce the conditions prevailing in any colliery with regard to the overlying strata. Therefore he failed to see how experiments in that direction could help much with regard to subsidences following coal-workings. The following Table showed the calculation of a few cases from the formula he had given:— Mr. Kay.

TABLE OF MINIMUM RADIUS OF PILLAR (IN YARDS) ACCORDING TO DEPTH OF SEAM AND THICKNESS OF EXCAVATION, CALCULATED FROM THE FOREGOING FORMULA $\left(r = \frac{\sqrt{3d} \times \sqrt[3]{t}}{0 \cdot 8}\right)$

Depth in Yards.	Thickness of Excavation.							
	2 Feet.	3 Feet.	4 Feet.	5 Feet.	6 Feet.	7 Feet.	8 Feet.	9 Feet.
50	19·3	22·1	24·3	26·2	27·8	29·3	30·6	31·8
100	27·3	31·2	34·4	37·0	39·3	41·4	43·3	45·0
150	33·4	38·2	42·1	45·3	48·2	50·7	53·0	55·2
200	38·5	44·1	48·5	52·2	55·5	58·4	61·1	63·5
250	43·1	49·4	54·3	58·5	62·2	65·5	68·5	71·2
300	47·3	54·1	59·5	64·1	68·1	71·7	75·0	78·0
350	51·0	58·4	64·3	69·3	73·6	77·5	81·0	84·3
400	54·6	62·5	68·7	74·0	78·9	82·8	86·6	90·1
450	57·9	66·2	72·9	78·5	83·5	87·9	91·9	95·5
500	61·0	69·8	76·9	82·8	88·0	92·6	96·8	100·7
600	66·8	76·5	84·2	90·7	96·4	101·5	106·1	110·3
700	72·2	82·6	90·9	98·0	104·1	109·6	114·6	119·2

Mr. Kay. These dimensions, as stated previously, were for pillars under normal conditions, and were intended to be set out in plan, from the exterior points of the structure to be protected. He feared, however, the citing of all cases during his experience, upon which the formula was founded, would not only occupy much space, but would need many illustrations to show in an instructive manner the precise elements of each case. Having regard to the fact that the formula had met with general acceptance, he would suggest it to be taken as embodying all he could show in such an appendix. In conclusion, he considered the question of support to be one requiring all the skill and prudence of the mining engineer to determine, combined with experience in the investigation of the effects of subsidence both in their geological and physical aspects, and in the observance of any accompanying conditions which might tend to mitigate or exaggerate the risk of injury to the surface.

Correspondence.

Mr. Brough. Mr. BENNETT H. BROUGH considered the subject of the Paper one of great importance to mine surveyors, and the results of the long experience there recorded formed a valuable contribution to the solution of a problem that had not received in England the attention it deserved. On the Continent elaborate investigations had been conducted by Callon,[1] Fayol,[2] Hausse [3] and others. In Germany the size of the pillar was determined by the angle at which the bounding planes of the broken mass were carried to the surface. In Westphalia, for example, it was usual with seams dipping at 45° to assume that the angle was 65° to 75°. From a careful study of the subsidence occurring in the Saxon coalfield, a Table [4] had been constructed showing, for seams dipping at various angles, the direction of the plane of fracture occurring on the breaking of undermined strata, as determined by the angle of fracture, or in other words, the angle made by the plane of fracture with the horizontal plane. This Table was constructed from the general

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[1] "Lectures on Mining," translated by W. Galloway and C. Le Neve Foster, vol. ii. London, 1881, p. 304.

[2] Bulletin de la Société de l'Industrie minérale, vol xiv. p. 818.

[3] Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen, 1886, p. iii.

[4] "Treatise on Mine Surveying," by B. H. Brough. London, 6th edition, 1897, p. 273.

equation $\tan \phi = \frac{1 + \cos^2 \beta}{\sin \beta \cos \beta}$, in which ϕ was the angle of fracture, and β the dip of the strata. If β was equal to 0°, the equation became $\tan \phi = \infty$, and $\phi = 90°$; in other words, in horizontal strata the plane of fracture coincided with the line of gravity. When β was equal to 90°, the equation again became $\tan \phi = \infty$, and $\phi = 90°$; in other words, in vertical strata the plane of fracture coincided with the line of gravity. In the example given by the Author to illustrate the application of his empirical formula, the angle of fracture ϕ was $\cot \phi = \frac{68}{400}$; $\phi = 80° 21'$. The Author's formula would therefore appear to be in accord with the German theory, provided that the strata dipped at an angle of about 20°. Results actually obtained in practice confirmed the accuracy of the German theory. Thus for supporting the glass-works at Doehlen, in Saxony, a 25·6-yard pillar was left, but, nevertheless, the surface sank considerably. The coal seam dipped 12° and was 180 yards deep. Calculated from the depth and size of the pillar, the angle of fracture ϕ was found to be 82°, or 2° 20′ less than the result obtained from the theoretical formula. In another case in the same district the value of ϕ found practically was 82° 30′, or 1° 50′ less than that found theoretically. Mr. Brough.

Mr. T. FORSTER BROWN remarked that the circumstances under which subsidence took place varied so widely that it would often be unsafe to accept any fixed rule, without a varying margin of safety, increasing when the conditions suggested it. It was probably not safe under any circumstances to leave pillars of coal for surface support at greater depths below the surface than about 400 yards, when the coal, roof and floor were fairly hard; at greater depths the pillars would probably ultimately crush and the surface subside. At greater depths therefore, or at smaller depths when the coal seam, or roof or floor were soft, to secure the surface from subsidence, a pillar of solid coal should be left. The extent or area of this pillar to support a surface erection would be greatest when the superincumbent strata were soft, giving a flatter angle of rest, and somewhat less when the bulk of the strata are rock and the angle of rest steeper. The position of the coal pillar for support of a surface building, whilst perpendicularly below, but of wider area in flat inclination, was, in inclined strata, varied in position, being left more to the rise of the fracture of the strata, at moderate angles (not in very steep angles), the fracture being somewhat in the direction at right angles to the dip of the strata. In ordinary circumstances, in flat strata, for a depth of 500 yards, Mr. Brown.

Mr. Brown. the pillars should probably be one-tenth of the depth greater than the surface area plus a margin of safety of, say, 20 yards, equals 70 yards beyond the surface erections in all directions; in soft strata a larger pillar, and in hard strata a smaller pillar, would probably be safe. In inclined strata the subsidence to the dip was always more than to the rise, therefore a larger area is required to the rise. But these general rules had to be modified by the special circumstances in each case—thickness of seams, faults crossing the areas modifying the position, more coal requiring to be left on the rise side of a dip fault than on the dip side. If unconformable strata, such as the magnesian limestone or new red sandstone, overlay the coal measures these introduced new conditions. Within his own experience he had known buildings affected beyond any usual angle of rest where the coal workings were inclined away from the building, and under the building near the surface existed a moderately thin bed of hard new red sandstone. A safe guide to the angle, which should be adopted, was the angle at which slip faults were found to exist in similar strata in the particular locality. In iron-ore mines it was found, as at Hodbarrow, in South Cumberland, new conditions again existed; there, the iron ore was overlaid by a thick bed of gravel and sand, and whilst in ordinary working the drag or subsidence of surface assumed a very flat angle, extending at the surface far beyond the face of working, under some circumstances, owing to the drainage of the sand and water, subsidence had taken place at a great distance beyond the outer edge of the surface drag line and had let down the sea embankment, which was designed to shut out the sea at a considerable distance outside the extreme limit of any expected possible surface subsidence.

Mr. Gillott. Mr. THOMAS GILLOTT recognised the great importance of the subject introduced by the Author, with whose conclusions he was in general agreement. He had, however, little hope that surface owners would modify the position of intended buildings to meet the conditions shown by *Fig. 1.* An almost identical instance was that of an important structure where the depth of the seam was about 450 yards, the horizontal projection of the fault 400 yards, and no damage had been apparent 3 years after removing the coal, a barrier pillar 22 yards wide having been left along the toe of the fault in a 3 feet 6 inches seam. As to the proportion of the thickness of the seam removed, which was accounted for by surface subsidence, he was doubtful whether the full settlement indicated on *Fig. 2* had taken place at the date of levelling, and he thought that as the workings extended, and after a further lapse of time, there would be further settlement, assuming

Mr. Gillott.

that by 70 per cent. and 64 per cent. respectively the maximum subsidence is given for each case. He considered the formula given (on p. 121) unsound, inasmuch as it fixed the radius of the pillar by the product of a root of the depth into one of the thickness of the seam, with a constant multiplier. The Author correctly stated that the effects of working shallow pits were soon apparent on the surface, and had introduced the thickness of the seam as a factor to determine the radius of the pillar; but the pillar required should be determined for support directly as some power or fraction of the depth, and as the drag diminished with deeper workings, an addition should be made for it. The equation would then be of the form:—

$$r = m\,d_p + n\,\frac{t_q}{d^r}.$$

It was, however, very difficult to devise any rule for pillars applicable even to the generality of cases. At one colliery the depth below the surface was 80 yards, the thickness of the seam 5 feet 6 inches, and an important building had to be protected. The upper layer immediately below the surface was limestone rock, and by the Author's formula the value of r was 34 yards; a pillar of 55 yards was left all round, but the surface was badly cracked at 11 yards from the building. It often happened that (1) after one seam had been worked others were worked at a lower level, or (2) a thick upper seam was reserved entire for support of building land with a right reserved to work certain thinner and deeper seams. In the first of these cases the disturbance by working the lower seams caused much more damage than that done by the same seams in the second case. As instances, the working of three seams of 7 feet at 112 yards deep, 4 feet at 288 yards, and 4 feet at 475 yards, resulted in serious damage when the lowest seam was worked after the two upper seams, whereas, when the upper of these seams was left unworked, the extraction of both the lower seams could not be perceived in buildings under which the coal was taken. In the first of the two cases, the values of r calculated by the Author's formula were 44 yards, 58 yards, and 75 yards respectively, whereas in the case (1) referred to 110 yards proved insufficient for the lowest seam. If the coal was worked to the rise, the distance K to F should be added to the pillar shown on *Fig. 4*. He was aware that pillars had been ribbed, as shown by *Fig. 5*, but unless they were stowed solid, there was no certain support for a lengthened period, and the saving effected by removing part of the mineral was very doubtful.

Mr. Graves. Mr. H. G. GRAVES observed that of the many aspects under which the question of subsidence had been considered, the Author had chiefly been concerned with the action on the surface. The effect on the underground workings had been dealt with in a recent Paper by Mr. Joseph Dickinson.[1] The subject had also been treated by Professor W. Galloway[2] in a Paper which, in its more important features, was a translation from a classic memoir by Fayol,[3] who, before 1885, made an extended series of experiments with models, and a lengthy series of observations in the Commentry coal basin, similar to those made by the Author. Experiments with models could only be utilized to determine general questions, and were quite unsuitable to solve the problem of what would happen in particular cases of underground workings, as it was obviously impossible to reproduce on a small scale the conditions with even approximate exactitude in view of the nature of strata, which might vary from yard to yard. Fayol's experiments were made with models in which strata were simulated by layers of sand, clay, plaster of Paris, and other materials superposed on laths which were drawn out one by one. Into the void spaces thus produced the superincumbent layers settled and the amount of distortion at the surface and inside the mass could readily be investigated. The strata affected by the settlement over worked-out areas were included in a dome, which gradually expanded as the workings proceeded. When the strata were level, the axis of the dome was vertical; when they were inclined, the axis was inclined and lay somewhere between the vertical and the normal to the strata. The strata immediately above the workings yielded most and the area affected at first gradually extended as higher strata were reached, and then diminished again until it died out altogether before the surface was reached. This was accounted for by the fact that the broken material occupied more space than the solid, so that beyond a certain height there was no void calling for subsidence. The Author adopted a limiting area for subsidence depending of half the angle between the vertical and normal, and this might be taken as including the average with a margin in addition. In this way theory and practice might be considered as fairly coincident. The experiments made on these lines by Fayol and others had been very extensive, and it would not seem as if much further light could be shed on the question by continuing them.

[1] Transactions of the Manchester Geological Society, vol. xxv. pp. 583–612.
[2] Proceedings of the South Wales Institute of Engineers, vol. xx. p. 304.
[3] Bulletin de la Société de l'Industrie Minérale, 1885, Series II. vol. xiv. p. 805.

For the more exact correlation of subsidence and working an exact series of observations was necessary in different districts, showing the change of surface-level, the depth and thickness of the workings, and the composition of the strata overlying the workings. In many cases, where several seams were worked, a series of underground level changes could also be obtained. At present it was considered that the superincumbent strata were of generally a certain nature; and if further details were required, their exact nature must be found from borings and sections. The solution of any given problem of subsidence depended on many and variable factors, but it would seem that more attention should be given to this factor of the rocks themselves. Mr. Graves.

Mr. H. Ashton Hill, whilst agreeing with the Author's general conclusions, considered that his estimate of time required for complete settlement of the ground after mining, from 2 to 3 years in mines not more than 100 yards deep, inadequate. In the South Staffordshire district it was difficult to obtain ideal sites for reservoirs, and it therefore became necessary to make the best of such as were available. He had recently completed the construction of a $3\frac{1}{4}$ million gallons covered reservoir on a foundation of old pit workings. Before deciding upon the site, careful inquiries were made as to the dates of working the several seams of coal. No workings had taken place for a period of 34 years, and the evidence of miners who had been in the workings, was to the effect that the roads under the land in question were pretty well consolidated. The shafts from which the mines were worked were filled in 1874. The greater part of the thick coal (67 yards below the surface) was worked prior to 1843. The pillars left in these workings were worked about 1858 to 1861, the old roads being filled with gobbing. In 1845 the heathen coal (7 feet below thick coal) was all worked out. In 1862 the brooch coal (about 26 yards from surface) was worked out, since which date there had been no mining. It was decided to purchase the land and construct the reservoir; the work was commenced in October, 1896, and the excavation revealed for the most part a bed of very tenacious clay, but the outcrops of two seams of coal showed in the bottom and means were taken to stop these out. The reservoir was completed in February, 1898, and was filled with water, when a slight leakage was discovered. Upon emptying, an examination was made and small cracks were found, evidently due to settlement caused by the weight of the structure and the contained water. The amount of settlement, which was fortunately fairly even over Mr. Hill.

Mr. Hill. the whole area of the ground, was between 1¼ inch and 2 inches. The reservoir was then rendered with cement, and refilled in June 1898, and it had since remained perfectly sound. From this experience it would therefore appear that the ground had not become solid after a lapse of 34 years. Another reservoir under his control, of a capacity of 43 million gallons, was constructed over an unworked coalfield in 1877. Subsequently the shallow coal, 8 feet 3 inches thick and 400 yards deep, was mined underneath it; and the deep coal, 6 feet 3 inches thick, 22 yards below the shallow, was also mined to within 50 yards of the reservoir. In this case there was a fault running through the reservoir, with the result that subsidence had taken place much more on one side of the fault than on the other, and there was now a difference of level between two points on the bank, which were originally on the same level, of 4 feet. During the last 12 months, moreover, the 6-foot coal, which was 80 feet above the shallow, had been worked. It had therefore been considered advisable to fill the reservoir to about only half its total height of 22 feet, for fear of a sudden cracking from the settlement due to the mining which was still proceeding. Another reservoir in his district was affected by coal mining and also by an adjacent basalt quarry, which, together, had caused subsidence, contortion, and also large cracks in the sides of the reservoir, and the watertight capacity was now only some 800,000 gallons, whereas the reservoir was built to hold 3,250,000 gallons. In the construction of these reservoirs the bottom and sides were well puddled and thus allowed a certain amount of give, otherwise it would have been impossible to have used the reservoirs. Wherever there was a likelihood of future mining and consequent subsidence under the site of a proposed reservoir, clay puddle should be used in its construction, as a purely concrete and masonry structure would, under the conditions described, be rendered absolutely unserviceable. The frequent breakages of pipes through subsidence was an important matter. In mining districts plain spigot-and-socket pipes should be used in preference to turned and bored, the lead joint allowing a certain amount of play before the pipes were damaged or leakage took place. During the process of subsidence the tendency was for the joints to be drawn, then after a time the contrary effect ensued, the ground closed in, and the spigot ends were forced hard into the bottom of the socket, the result being great distortion of the pipe line. By careful watching the pipes could be bared from time to time, the line straightened and the joints set up. At other times the dislocation was so sudden as to cause fracture and its attendant inconvenience. In some

districts, at Whitehaven, for instance, crownings in of a more serious character took place and the pipes were dragged down to considerable depths. Great as was the damage to water mains in mining districts, that to gas mains and sewers was still more serious, as the alignment of the former might be interfered with to a greater extent before any evil consequences resulted. Mr. Hill.

Mr. HERBERT W. HUGHES considered that any facts relating to probably the most intricate problem in mining were acceptable, and that the Author's observations on the subsidence caused by the cases which had come under his notice were valuable, although it was probable that the deductions drawn would not be accepted as affording a solution of even a small number of the cases of damage resulting from mining operations. On no other question relating to mining had so many contrary opinions been expressed as on the effect of coal workings on the surface, both as regarded the extent of the movements and their direction. As regarded the former, statements had been made (*a*) that movement extended to the surface without sensible diminution whatever might be the depth of the workings; (*b*) movements became more and more feeble as they extended upwards, and ceased entirely when the workings exceeded a certain depth; and upon the relative positions of the mining excavation and the surface subsidence, (*a*) subsidence always took place vertically above the excavation, (*b*) was limited by lines drawn from the perimeter of the workings and "normal" or perpendicular to the inclination of the beds, (*c*) could not be referred to the excavation either by vertical lines or to the normal of the beds, but only to lines drawn at an angle of 45° to the horizon, the angle of repose of the ground, or some such similar angle. In his lectures on mining at the Paris School of Mines, Callon first drew prominent attention to the theory of the "normal," viz., that subsidence took place at the perimeter of the excavation at right angles to the plane of inclination of the beds, and that theory was accepted by Dumont after an examination of the subsidences caused by working beds of coal in the neighbourhood of Liége.[1] Unfortunately the correctness of Dumont's observations was questionable, owing to the fact that they were conducted at a point where old mining operations had taken place, and that in addition several collieries were working in a very small area. The Colliery Owners' Association drew up a reply [2] disputing them, and expressed the Mr. Hughes.

[1] Des affaisements du sol produits par l'exploitation bouillère, pp. i–xxxviii. and 1–336, Plates xxvi. Liége, 1871.

[2] *Ibid.*, pp. 1–335, Plates xxii. Liége, 1875.

Mr. Hughes. opinion that, while the law of the normal might sometimes be correct with seams of small inclination, the propagation of a fracture following the perpendicular to the stratification of highly inclined beds was a mechanical impossibility, because account must be taken of the fracture by crushing, which, according to Coulomb, takes place at 45°. The combination of this force with that tending to break the bed by bending induced fracture along a line intermediate between the two directions, and such line went further from the normal as the inclination of the strata increased. This diversity of opinion among engineers led Mr. H. Fayol to review the whole subject.[1] He not only examined a number of actual cases resulting from working the seams at Commentry, where such observations could be made free from all complications, but conducted a series of experiments on models, which reproduced on a small scale movements in the overlying strata caused by working beds of coal in such a manner as to be able to observe the progress of events. The apparatus consisted of a wooden box having a glass front, on the bottom of which were placed side by side small pieces of wood of equal thickness about an inch wide and as long as the width of the box; several rows of these small pieces of wood were sometimes placed one above the other. Upon them were laid successive beds of artificial strata, varying from $\frac{1}{24}$th inch to 1 inch or more in thickness, and consisting of earth, sand, clay, plaster, or other materials. To enable the least movement to be followed small pieces of paper (about $\frac{3}{4}$ inch long) were laid in the planes of stratification, and ink lines were drawn on the glass front of the box exactly covering the lines formed by the paper strips. When the small pieces of wood were withdrawn one by one, excavations were formed and movements produced in the overlying strata. Further experiments were also carried out to determine the plane of fracture of rocks, when it was found that in 80 per cent. of the observed cases the line was an inclined one instead of being at right angles. All the experimental results and observations of actual subsidences can be explained by the following rule: in stratified deposits the zone of subsidence was limited by a dome, which had for its base the area of excavation; the extent of the movement diminishes the further one goes away from the centre of that area. If the beds were horizontal the dome was arranged symmetrically round its axis, which was vertical. Each of the beds included in the

[1] "Note sur les mouvements de terrain provognés par l'exploitation des mines." Bulletin de la Société de l'Industrie Minérale. St. Etienne. 2e Serie, vol. xiv., pp. 805–871.

dome sank in the form of a basin, and the extent of the movement diminished in proportion as it was further from the centre of the excavation. This statement was supported by *Fig. 2* of the Paper. If the beds were inclined the dome was no longer symmetrical, and its axis was inclined. In proportion as the seams became more inclined the axis of the dome was inclined also, and tended towards the horizontal; at the same time the height of the zone of subsidence tended towards zero. Vertical, normal, axis of figure of dome, and line of maximum subsidence all coincided when the beds were horizontal; they were distinct when the beds were inclined. The direction of the axis of the dome must not be confused with that of its limits (*i.e.* the circumscribing lines of the dome). Sometimes the axis approached in a remarkable manner the perpendicular to the strata, and it was this, perhaps, which gave rise to the theory of the normal. Although opinions were so divided, the differences were more apparent than real, and in the majority of instances were the result of generalizing from single facts which were only particular cases of Fayol's rule. The amount of subsidence was dependent on the nature of the overlying rocks, the depth of the excavation below the surface, the thickness of the seam, and the nature of the material used for packing or stowing. The compressibility of different materials varied, and subsidence would naturally be less in extent and more gradual over portions carefully packed with hard compact sandstone than where the stowing consists of soft shales. The subsidence the Author mentioned of 70 per cent. of a 5-foot seam at a depth of 360 feet, and of 64 per cent. in a 3½-foot seam at a depth of 990 feet, were rather larger than expected, although experiments at Bent Colliery, Scotland, on a 5-foot seam at a depth of 670 feet proved a maximum subsidence of 73 per cent. At Montrambert and La Bérandière a shrinkage of only 30 per cent. took place, but this low result was possibly due to the peculiar method of working. At Bully Grenay, after six seams, of a total average thickness of 29·36 feet, had been worked, the total subsidence was 13·61 feet, equal to 46 per cent. of the height of excavation. The varying results might possibly be due to the fact that observations had been made at different parts of the excavation, as subsidence was always greater at the centre than at the circumference. The occurrence of faults might introduce the greatest complications. Where the beds were covered with drift of a soft, loose, sandy material, the area of subsidence might be unlimited, especially if the deposit contained water. In one such case, with workings at a depth of 840 feet, buildings were damaged very considerably at

Mr. Hughes.

Mr. Hughes. a distance of 660 feet from the limit of the excavation. The drainage of old workings, or the flooding of a mine, often brought about fresh movements a long time after the original ones had ceased. In South Staffordshire neither the railway nor canal companies purchased mines except for the support in a few instances of important bridges or tunnels. Thick seams at comparatively shallow depths were worked beneath canals without any special precaution, except in so far that the embankments of the canals were raised and re-puddled and the bottom filled in as subsidence took place. In such a manner 30 feet thick of coal had been taken out at a depth of only 432 feet, the subsidence produced being 13 feet 4 inches. While this was taking place the water remained in the canal and traffic was not interfered with, except on two occasions, when subsidence took place so rapidly that the staff of workmen employed could not raise the puddle to keep pace with the movement, and the water had to be temporarily taken off.

Mr. Longden. Mr. J. A. Longden agreed in general with the conclusions of the Author, but the Paper contained statements to which he took exception. He also thought the omission by the Author, in considering the site of the pillar to be left, of the centre from which the radius must be described, an important one. The Author's formula would be inadequate when the seam was thick and near the surface, and inaccurate when the depth was great and the seam of coal was thin. The shrinkage of the surface was stated to be about two-thirds the thickness of the coal, and under canals it was advisable to work it out and yet leave pillars under the locks. These small pillars under the locks would cause far more damage than if the coal was all cleared away and the space packed as well as possible, not by throwing the dirt behind the coal, but by building stone-wall packs filled in with small, in accordance with the practice at all well-regulated collieries. The site of the pillar should be nearly at right angles with the seam, and hence, on some of the Lancashire plans where steep mines exist, the pillar in the workings seemed to have no connection with the buildings it was left to support. The Author appeared to consider that because he ascertained certain shrinkage had taken place at 120 yards and 330 yards depth, therefore his findings must apply equally to all depths. A fallen roof in a coal mine showed clearly that the strata immediately above the excavated coal were broken up, and the next layer was bent badly, whilst the one above was merely bent, and a few yards up the strata did not show any sign of bending. This fact, applied to an increasing depth, demonstrated

that the subsidence at 1,000 yards, all other conditions being equal, could not be nearly so great as at 100 yards in depth. Before long all coal would be worked on the long-wall system, because ventilation was thus more easily secured and managed; the greatly-increased depth from which coal would have to be obtained in the future would make this a necessity, and further because that method of working produced a much greater proportion of large coal, and the long-wall system was specially adapted to the requirement of coal-cutting machinery; hence, in the future, railway engineers would probably advise stowing the goafs and not allowing pillars to break all the ground round their edges. Coal workings had been charged with far more damage to surface erection than they had any right to be. Recently a church in the Midland Counties was greatly damaged and no doubt coal workings conduced, but other property quite near was not in any way damaged, and it had been clearly proved that the church was built on a large sand crack in new red sandstone measures, and this was the primary cause of the damage. Then again a new bridge was built in the same parish to carry a railway over a road, and the engineer, knowing coal would be worked there some time, put in deep concrete foundations and ran old rails the full length of the piers among the concrete; he was satisfied that would never move, and was much surprised when he was informed the bridge was gradually sliding downhill. When, however, he found the coal all solid for more than ½ mile from the bridge he knew it was a soft bed of clay with water near it which caused the slipping. About sixty piles were driven in the ground on the low side of the bridge, and no further movement had taken place and probably would not do so long as the piles remained sound. Mr. Longden.

Mr. JAMES H. LYNDE remarked that, 30 years ago, while he was acting as Resident Engineer, under the late John Addison, on the Wolverhampton and Walsall Railway, several bridges were built on land that was known to be subsiding in consequence of the removal of coal. Special precautions were taken to prevent the breakage of abutments and wing-walls. The rails were carried on wrought-iron girders and cross girders and buckled plates. The foundation was excavated sufficiently deep to allow of a bed of concrete 4 feet or 5 feet thick. On this was laid two courses of elm planking, each 4 inches thick, on which the brick footings, four courses, were built, and on these four courses was laid a hoop-iron interlaced frame, 4½ inches mesh, extending over the whole of the abutments and wing-walls. This arrangement Mr Lynde.

Mr. Lynde. was repeated every four courses. The result was that, although as much as 3 feet or 4 feet of subsidence had occurred in some cases, the whole bridge sank in a mass, unbroken. It was only necessary to keep a gang of men lifting the road and girders and build extra brickwork and bedstones under the girders. He had seen these bridges some years after they were built, and he could not find a crack.

Mr. Paterson. Mr. MALCOLM PATERSON thought the subject of subsidence from coal-workings had never yet been adequately treated, and the present Paper was a thoroughly practical contribution towards that end. His own works lay amid coal-workings, and he had a curious experience of its effects. At Ravensthorpe, in the Calder Valley, sewage works he had constructed 24 years ago remained intact for over 20 years; they lay on the verge of a colliery leasehold. In August, 1897, the effluent outlet submerged 15 inches below the ordinary level of the stream into which it discharged. At his previous visit it was at its normal level, of about 6 inches above the stream. The settling-tanks were cracked across the centre, and the tank sewer, he was informed, had settled considerably. These settlements arose from the getting of a 20-inch seam of coal, besides the dirt, about 50 yards to 60 yards deep, and the boundary of the worked coal terminated in or near the sewage works. In the same year, a similar disturbance took place at the Castleford sewage works in the same valley, carried out by him in 1878. Complete re-levellings of the three roads intersecting the land were taken, and proved an average settlement of 3·3 feet throughout nine-tenths of the 12½ acres of sewage land, without the surface being broken. In this case the getting of the Warren house coal, 4 feet to 4½ feet thick, at a depth of 201 yards was the cause, thus corroborating the Author's statement in two important points, viz., the non-rupture of the surface at this depth, and the proportion of subsidence to the thickness of coal. Further, although the stoppage of certain subsoil drains might be laid to the subsidence, apparently none of the main effluent drains were affected. The contour also was singularly constant, the new sections being almost parallel with the original sections. The strata here were the shales and sandstones of the coal measures, overlayed by the marls and limestone of the Permian formation, and the pit shaft was only about 75 yards from a brick shed on the sewage land, at which, however, the settlement was trifling with no visible damage. It might be added, that in preparing to win a lower seam, the Beeston bed, 578 yards deep, a pillar was to be left, 13 chains square, round the shaft, or, say, 250 yards each way from its perimeter. As to the design of structural

works, and especially hydraulic works such as reservoirs, the cautious procedure advised was correct; but in many cases the cost and difficulty of purchasing the pillar of coal were too great. At present, from a combination of causes, but chiefly owing to the getting of a deep seam of coal below a site already honey-combed by excavations of moulders' sand only 30 yards or 40 yards deep, the Castleford service-tank was split across the centre by a chasm 27 feet deep and 2 feet to 7 feet wide. In reporting recently upon the reconstruction of the tank on its present site, owing to the difficulty of procuring a much safer site, he proposed to deepen it so as to get below the honey-combed crust of the old sand-workings, thus making the tank four times as large. It was circular, and would then be 76 feet in diameter, and $42\frac{1}{2}$ feet deep, holding 1,200,000 gallons. It was to be of cement concrete throughout, lined with bituminous cement, and bound with $\frac{3}{4}$-inch disused steel colliery rope at every 12 inches vertically and horizontally. This rope, under colliery regulations, could often be obtained almost as good as new for this purpose. The concrete was to be exceptionally thick. It appeared that authorities possessing drainage works, sewage works, and waterworks might fairly claim the right of notice before working, and option of purchase of coal, accorded to railway and canal companies. Mr. Paterson.

Mr. F. EWART ROBERTSON cited, in reference to the subject of the Paper, the case of the East Indian Railway, where the main line for many miles passed through the colliery districts of Bengal, and the workings of collieries adjacent to the line were a continual source of anxiety. In olden times the plans of those collieries were very defective, and in some cases there were none at all; but now that the industry had assumed important dimensions that matter had been adjusted, and the Company's engineers had reliable plans of the workings which were approaching the line, and they were examined about twice a year. The information given in the Paper would be an aid in determining the safe limit of working. In one case a branch line had to be carried over some abandoned workings which lay at a very shallow depth. They were of the usual native style—about half the coal left in as irregular pillars, each so small as to be unsafe. These workings were packed with stone and the place had stood for some years. How serious a matter a settlement would be in these cases would be shown by the fact that the seams were between 10 feet and 25 feet thick, and the depth was only about 100 yards. There was in one place an outcrop of good coal 90 feet thick. Experience in the Mr. Robertson.

Mr. Robertson. East Indian railway collieries confirmed the Author's statement as to the gradual advance of a settlement doing but little harm, while a stoppage in work started trouble at once. Although the seams were so thick and shallow, yet houses, and even chimney stacks had been dropped several feet without material damage, and the former had been re-occupied after the settlement had ceased. This was probably due to the excellent roof, which was clean, strong sandstone, from the coal up to the grass. When however, the working had stopped, as at the boundary of a property, the roof after a time broke down and cracks appeared at the surface. No attempt was made to pack these huge goafs, as the floor and roof were both clean stone, and all the coal was won that it was possible to get out. Whether designedly, or accidentally, the numerator of the Author's formula $\sqrt{3\,d} \times \sqrt[3]{t}$ formed an excellent *memoria technica*, and the corrections for inclination of the strata seemed as clear as was possible with such a complicated subject. With reference to the style of structure best suited to resist settlements, there was at Rewari, near Delhi, a hard, very coarse-grained sandstone which was quite elastic. A bar of it, say 12 inches by 2 inches by $\frac{3}{4}$ inch, would, if laid on supports, bend considerably, and a longer piece if held vertically in the hand and shaken would vibrate like a leather strap. Such a stone would be invaluable in districts subject to subsidence.

Mr. Shelford. Mr. W. Shelford had had to deal with the question of subsidence in various places, especially in constructing the Hull and Barnsley Railway across the South Yorkshire coalfield, which it traversed for a distance of about 12 miles. The expediency of purchasing the coal under the principal works was considered, and the idea was discarded on account of the great value of such seams as the "Barnsley Steam" and the "Silkstone House" coals. It generally did not seem necessary to alter the construction of the bridges except in matters of detail and in the avoidance of arches, especially in positions where they could not be propped up from substantial centres in case of need. The Author appeared to advocate well-tied abutments and wings for bridges, but he did not state whether he meant that they should be bonded separately in detail, or bound together to make a substantial whole. The view upon which he had acted in many bridges was the separation of the masonry or brickwork into parts, which should subside independently of each other, but should have the materials in each part bonded together. On this principle he had designed and built several bridges with abutments and wings, separated only by a straight joint without mortar, which was concealed by a pilaster,

so that any moderate movement in the structure would be invisible, and that in any case the abutment should stand when the subsidence occurred. The largest of these bridges was at the crossing of the Dearne River, about 1 mile below the point where the Midland Railway Company's line to Barnsley had been built over it on an iron-braced viaduct, for which the coal had been purchased underneath and on each side. He had reason shortly to expect subsidence in this valley, and had therefore obtained power to abandon a viaduct, which had been authorized, and to substitute an embankment pierced by bridges, of which the one over the river was the chief. In this bridge the abutments were solid and well bonded together by hoop-iron carrying a double line of railway on iron girders. The wings, which were curved, were abutted against the back of the abutments with a straight joint, and all connection between the two was carefully avoided. This work was carried out about 1884, and Mr. Pawley, the engineer of the company at Hull, stated that "the subsidence due to the extraction of the Barnsley coal occurred in 1891 to the extent of about 3 feet, and all four wing walls separated from the abutments, but the abutments themselves remained uninjured and subsided bodily, the result being that they are now only 3 or 4 inches out of the perpendicular. As soon as the subsidence was over the wings were partly rebuilt, and there is now nothing to indicate that the bridge had ever been disturbed." The principle upon which they were designed had therefore proved so far to have been successful. Mr. Shelford.

Mr. A. Sopwith thought the Author had made an omission in not referring to the important bearing that the immediate surface deposits, lying over the bed rock, had upon the subject. Again little attention was called to the variation in the nature of subsidence and draw which might be expected under different conditions of the measures, though this was perhaps covered in the general remark as to variation in different localities. It was impossible to reduce such different conditions to definite standards, but they might be classified, for the sake of illustration, under three heads:—(1) Measures consisting of fairly equal proportions of rocky and argillaceous beds, and containing thick beds of sandstone; (2) when the proportion of rocky beds was small, say 15 per cent., and only thin beds of sandstone exist; (3) variations between these two. The tendency in the first case was for the edge of the subsidence to follow or lie over the excavation; in the second to be over the solid coal. In the third there would be more Mr. Sopwith.

Mr. Sopwith. or less close approximation to the conditions named by the Author. The area of pillar given by the formula might be taken as near enough to the requirements, but some modification was necessary to meet the more extreme conditions. The surface contour, and the nature of the surface soil and upper deposits, were, however, specially important factors, and bore as much upon the subject as any of the conditions connected with subsidence. Considerable experience of working under ordinary mineral line railway bridges, embankment culverts, houses, farm buildings, enabled him to corroborate the statement that under favourable conditions, say freedom from large faults and not very highly inclined measures, little or no damage resulted from working out all the coal, and this, notwithstanding the subsidence, might amount to several feet. He had worked two seams of coal of about 6 feet each at a depth of 300 yards from the surface, under a pair of pits fitted and used for pumping and winding from upper seams 150 yards deep, without material injury to any of the plant. In the same locality these seams were worked to the extent of 45 acres, and at an average depth of 120 yards under a reservoir of 180 acres, a rib or boundary line being left along the centre for a distance of 1,200 yards. Under some acres four seams were worked, and the surface subsided 10 feet, the top seam worked being within 65 yards of the bottom of the reservoir, and within 57 yards of the sand and gravel bed forming the superficial deposit, a bed of clay, however, intervening between the gravel and the actual measures, which consisted principally of argillaceous strata, with few and thin beds of sandstone. The conditions in the first-mentioned case were similar, excepting that there was little gravel. He would hesitate before working out the coal when such serious risks were involved if the conditions had been reversed, say that the measures had been rocky, and coming close to the foundations in the one case, and the bottom of the reservoir in the other. At a time when the workings in one of the seams were approaching in a line parallel with, and towards the, edge of the reservoir, but some little distance within high-water line, it happened to be an exceptionally dry season, and the water was some 12 feet or 14 feet below weir-level. The margin of the reservoir sloped very gently, but parallel cracks were shown on the surface corresponding with each weight felt underground. These cracks were 6 inches to 8 inches wide, and ran down as far as one could reach with arm and stick, but gradually closed up as advancing breaks took place. This combined action of subsidence and drainage illustrated in a comparatively miniature

manner what took place when very thick beds of gravel were subject to deep drainage. Similar cracks, but on a very much larger scale, existed throughout the district, and in some cases assumed very large dimensions where workings were carried on under loose conglomerate hills which sloped rapidly. Drainage alone would cause cracks or openings in a gravel bed, but it naturally followed that the effect was more marked when such drainage was combined with subsidence. At the same time the displacement was not likely to be more than would be sufficiently equalized by the weight of a substantial building, excepting in some of the more extreme conditions pointed out. The same remark applied when the surface deposit consisted of clay, there being the same tendency towards relief if a building was sufficiently massive to weight down. Under such conditions solid arch bridges were probably as well able to withstand damage from sinking of the ground as girder bridges; if any apprehension was felt, safety could be assured by laying down strong baulks of timber over ordinary bridges until the ground was sufficiently settled. A greater danger than the collapse of a bridge, which, if it took place, would be gradual, was the possibility of insufficient allowance being made for expansion of rails. The joint action of a little extra and sudden subsidence and great heat might quickly put rails out of all guidance, and this applied particularly to cases where workings were near the surface, and if the top seam of the measures was being worked. The converse to the conditions alluded to, that was, either a plastic or yielding surface deposit, was found in the existence of a rocky or indurated bed of "short" nature as a foundation—in such case, there was a chance of damage resulting from displacement being, in the Author's words, severe and eccentric. Structures under such circumstances should be massive, but free play should be allowed for any movement of connecting beams or girders. Displacement under ordinary conditions would naturally not be great at any one time, but, even if small, the sudden and vibratory shock which might take place would tend towards rupture if the construction was too rigidly bound together. Probably more of the eccentricities of subsidence were due to the nature of the surface deposits and conditions than anything else connected with subsidence in its direct mining aspect. Mr. Sopwith.

Mr. A. L. Steavenson thought the immense number of conditions which governed the results, and the impossibility of bringing them into account, rendered the solution of the question onsidered in the Paper a matter of great difficulty. This was no Mr. Steavenson.

Mr. Steavenson. doubt the reason for the entire absence of all reference to the matter in the standard books upon coal-mining. The earliest and almost the only note upon the subject he possessed was an extract taken from the *Mining Journal*, so far back as 1861, and there the same view was taken as to the necessity for leaving coal on the rise side, rather than under the building to be protected. Notwithstanding this concurrence of opinion, cases could be cited in which it was necessary to leave the greatest area of support on the dip side, the ground naturally sliding downwards; in fact, surface conformation, and especially the nature of the surface, was perhaps of more importance than any other circumstance; thus large areas in the northern coalfields of Durham and Northumberland were deeply covered by glacial drift. In 1863 a lengthy and valuable Paper on this deposit, was given by the late Messrs. Nicholas Wood and Edward F. Boyd,[1] plans and sections were supplied, by which it was shown that in the vicinity of Durham it varied between 150 feet and 300 feet in thickness, and the worst feature was that the lower part of it consisted of gravel and sand, extending in all directions except on the hilly ground, for hundreds of square miles. His own experience led him, in the case of a valuable building and under average conditions, to leave an area of coal having a diameter equal to the depth, or half the depth on each side, and then to make passages through it, depending on the thickness of the coal and the surface conditions, which would afford from 30 per cent. to 50 per cent. The sections given in *Figs. 2* were interesting, but they did not afford such clear ocular demonstration as that given by walls. He had had occasion, some 10 years ago, to work a 3-foot seam at a depth of 160 yards round three sides of his house; long garden walls extended east and south, and on these was registered, in the clearest possible manner, the approach of the subsidence. The above rule had been applied, but owing to there being 40 feet of surface clay, cracks, although not of much importance, extended up to the house, and after the lapse of 10 years a slight movement still continued; in fact, unless the owner or tenant refused to be disturbed, the cases were few and far between in which it was not better to take out the whole of the mineral and repair or rebuild. One of the most serious forms which claims for damages for subsidence took was that of deprivation of water, and this led to the observation that if mining literature was deficient in treatment of the question, such deficiency certainly did not

[1] North of England Institute of Mining Engineers Transactions, vol. xiii. p. 69.

prevail in works treating of the law on the subject. Mine-owners were continually harassed by the most unreasonable claims. On one occasion a farmer alleged that, although he could not point out any change in the level of the surface, that the nature of the grass had been altered, and the cattle would not eat it. On another, the surface was said to have subsided over several fields, and it was only when the plans were produced showing that no workings had approached within a mile of the place that the claim was ended. With respect to the formula for the radius of support, it would appear that, instead of taking 3 *d* to represent the depth in yards, it was better to take *d* as representing depth in feet, but experience was the best guide. Mr. Steavenson.

Mr. EDWARD B. WAIN agreed with the Author that where coal was worked by a regularly moving face, as in the case of "long-wall" workings, there was the least possible risk of damage to surface erections. In such case, after a depth of 250 yards to 300 yards was reached, the subsidence was even and regular, and, except in the case of buildings containing machinery, or of brick, etc., arches, no serious ill-effects would be noticed after the subsidence had ceased. Where, however, the depth from the surface, or the nature of the surface erections, was such as to make it imperative that coal should be left for support, he thought that the formula given by the Author did not allow sufficient margin, a pillar of 68 yards radius at a depth of 400 yards being smaller than was usually left at that depth in most coalfields, and it was well known that an insufficient pillar often caused more serious fracture to surface buildings than no pillar at all. As had been pointed out in the Paper no absolute formula could be enunciated which would apply to all cases, owing to the varied character of the strata and of the methods of work; but he thought that the all-important factor to be considered was the natural slope or, to use a better term, the "angle of repose" shown in fracture by the strata overlying the coal worked. Where, for instance, the surface stratum consisted of soft or sandy marls the area of disturbance from mining operations would be largely increased. It was not difficult to approximate the angle of repose in the coal measures of any district, as the line of fracture shown by the faults or natural breaks in the strata might generally be taken as a guide. The faults in the Midland coalfields showed approximately an angle of about 1 in 5 from the vertical line, and their line of fracture was irrespective of the plane of stratification. If this angle was taken it would allow a safe margin, and at a depth of 400 yards below the surface would Mr. Wain.

Mr. Wain. give a pillar of 80 yards radius as compared with 68 yards by the Author's formula. Assuming the strata to be ordinary coal-measures, with no abnormal thickness of surface marls or sand, such a pillar would be found to give sufficient protection from lateral disturbance beyond the actual point to which the coal was worked. There could be no doubt that this, the angle of repose, was the ultimate point to which disturbance would extend, and by laying out a cone or, better still, a pyramid with its apex under the point to be protected, and with sides inclined at an angle of 1 in 5 (say 11°) from the vertical line, it was simple to decide the size of pillar at any given depth of working in coal seams which lay horizontally. In the case of inclined seams, however, it was necessary to take into account the actual fracture which immediately followed the extraction of the coal which would naturally be in the line of least resistance, *i.e.*, at right angles to the dip of the mines or planes of stratification. A few years ago he had taken a series of careful measurements of the line of fracture in several seams of coal at varying depths lying at 16° to 18° dip.[1] At 200 yards deep the line of fracture following coal working in the overlying strata was 85° from the dip, at 280 yards 92°, and at 470 yards 96°. The difference at the varying depths was not in exact proportion, but this was probably due to the difference in the roof material, that at the greatest depth being of a relatively stronger nature. It appeared from these measurements that the greater pressure, due to gravitation, of the overlying strata at the greater depth caused the roof to break in a more nearly vertical direction, but that in each case it was not very far from a line at right angles to the dip. In *Figs. 4* the Author had taken a line between the line of vertical fracture due to gravitation and the line of first fracture at right angles to the dip, and by doing so had secured a sufficient area on the "rise," or higher side of the pillar. As regards the lower side, however, it did not appear to provide the necessary protection, and he did not consider it was safe to make the lateral displacement as shown, and suggested that a better method would be to lay out the line on the upper side, as shown by the Author, but on the lower side to treat the pillar as if in horizontal strata, *i.e.*, to lay off a line extending downwards from the area to be protected in the line of the angle of repose of the measures, say, at 1 in 5 from the vertical line. There was no doubt that the ultimate line of fracture from the pillar of solid coal left would be in

[1] Transactions of the Federated Institute of Mining Engineers, vol. iv. p. 33.

about that angle. Although the first break would be at right angles to the dip, or approximately in the direction of the line C H, in *Figs. 4*, the mass of superincumbent strata A C H overhanging from A to C would ultimately be broken off by gravitation to the angle of repose of the strata. In coal-mining in inclined seams it was usual to find distinct action from similar causes, long distances above or to the "rise" side of advancing workings, and he had often seen roadways badly damaged, in coal workings lying at 18° dip and about 400 yards deep, by workings in the same seam, but 50 yards to 60 yards to the deep, with a pillar of solid coal between of that width. Mr. Wain.

Mr. Kay, in reply to the Correspondence, said that many more levels had been taken than could be shown upon the sections in *Figs. 2*. The sections were intended to show the date of the commencement and termination of the movement at certain periods; when subsequent levels at those points were found to coincide with former levels, after a sufficient interval to allow for further settlement, the earlier date was adopted in estimating the time taken for full subsidence, and therefore Mr. Gillott's suggestion that there would in the above cases probably be further settlement did not obtain. He noticed Mr. Gillott considered the formula for support unsound; but he thought any formula for protection against subsidence which omitted a direct variation on account of the thickness of the seam or excavation would be misleading, and ventured to prefer his formula to the one suggested. He would point out that the results given by his formula should not be compared with ineffective pillars under conditions other than normal, without making allowance for the altered conditions. The extraction of such a thickness of coal as that mentioned by Mr. Ashton Hill was unusual, and therefore he would expect an unusual length of time to elapse before complete settlement took place. The case the Author had in his mind in giving 2 years or 3 years for the bulk of the settlement to take place was that of a mine of average thickness of 4 feet or 5 feet and not a series of mines, one of them 30 feet thick, worked at different times and aggravating the subsidence to an extent difficult to predict. He would say with reference to Fayol's theory that it would be more reliable were the strata forming the coal measures more uniform in character, and more free from slips and great joints, leading the break in their direction. He considered the "lie" of these slips and great joints as the ruling factor in determining the route the line of fracture took in its course to the surface. This naturally was the line of greatest weakness within the region of active pull or Mr. Kay.

Mr. Kay. subsidence, and might or might not coincide with the lines of Fayol. This line in mines inclined up to, say, 30° from the horizontal, was modified under the action of gravity to that of a resultant lying between the normal and the vertical, as stated previously. He thought Mr. Longden had failed to notice that the omission he took exception to was given in the example accompanying *Figs. 4*, viz., that the pillar must be left "all round the structure," or, in other words, from all outside points of the building to be protected. Thus, supposing the bridge had long wings, it might be considered expedient to protect the abutments only and take the risk with the wings, in which case the pillar would be laid out 68 yards all round from the outside corners of the abutments. He failed to see on what grounds Mr. Longden considered his formula inadequate for thick seams near the surface, and inaccurate when the seams were thin and the depth great. He had calculated the line of break that the formula would allow for in the case of a 30-foot seam worked at a depth of 50 yards, and found this to be at an angle of 46° from the horizontal, and surely this was a sufficient angle of repose under normal conditions. Then for the thin seam, assuming it to be 2 feet thick and 600 yards deep, the formula gave a pillar of 3 chains radius; and that from the Author's experience would be somewhere near the mark should it be necessary to leave a pillar for so thin a seam at that depth, and amply sufficient, assuming that Mr. Longden's view, that subsidence became so diminishing a quantity at great depths, was correct. He further did not state, in reference to locks of canals, that it was advisable to leave pillars under them in all cases, but that it was usual to do so; for unless the lock-gates and side walls were constructed in the first place abnormally high, it was necessary either to leave a pillar to maintain the height of the works in connection with the fixed water-level at those points, or rebuild the lock, and this was more a question of comparative cost, as a rule, than of damage. The pack walls, as built at most collieries, were of little use in preventing subsidence, as they were mostly composed of the binds and shales obtained from the falls of roof consequent upon the extraction of the coal, and even when well built had not sufficient strength to permanently resist the crushing force of the superincumbent strata. If, however, they were built of strong stone or other material, which might have to be brought from the surface, the result was more satisfactory and the subsidence greatly modified; although where a succession of seams was worked it could not be sufficiently modified to avoid,

in the case of canals, the risk of letting down the locks below water-level, unless specially designed in the first place to allow for subsidence. That there might not be so much subsidence from deep as from shallow mines was very likely, and at 1,000 yards it might be reduced to less than, say, one-half the thickness excavated; but as these great depths were not within the region of practical politics at present, the proportion of two-thirds might be taken as an average factor to work to in designing works where subsidence might be expected. Mr. Shelford's method of building the wings and abutments separate, or self-contained, was to be commended in the case of a large bridge with spreading wings, as the damage to bridges from subsidence was frequently at the junction of wings and abutment. If the pilaster could be built to successfully cover the gaping opening that might be left at the line of division, it was a method that commended itself to the Author, though for ordinary small bridges he presumed Mr. Shelford would not adopt it. That thick alluvial or drift deposits might extend over the area in which damage from subsidence might be looked for was undoubtedly true, and the occurrence of such conditions rendered it extremely hypothetical to forecast the line that the break or pull might extend to at the surface. He agreed with Mr. Sopwith that this phase of the subject was of importance, though the eccentric behaviour of the overlying drift, or newer beds, was difficult to follow, according to any law of subsidence, because breaks sometimes spread far beyond any natural angle of repose, as instanced by Mr. Forster Brown. Mr. Kay.

6 December, 1898.

WILLIAM HENRY PREECE, C.B., F.R.S., President, in the Chair.

It was announced that the Associate Members hereunder mentioned had been transferred to the class of

Members.

William Sutherland Abbott.
Samuel Hewitt Agnew.
William Robert Butler, M.E. (*King's Coll., Nova Scotia.*)
David Sing Capper, M.A. (*Edin.*)
James Warne Chenhall.
Charles Frederick Clough.
William Collen, M.A., B.A.I. (*Dubl.*)
Daniel Connery, M.E. (*Queen's.*)
William Ernest Dalby, M.A., B.Sc. (*Lond.*)
Maximilian Hector.
Thomas Holgate.
James Johnston.
Arthur Meyrick Moore.
Thomas Monk Newell.
Frederick Palmer.
James Stafford Ransome.
Alexander Stewart.
Benjamin Stockman.
William Lumisden Strange.
Alan Archibald Campbell Swinton.
Joseph Timmins.
Frederic Lumb Wanklyn.
John Alexander Wilson.
William Henry Wolff.
Wilson Worsdell.
Thomas Henry Yabbicom.

And that the following Candidates had been admitted as

Students.

Robert Donald Thain Alexander.
Mir Ahmed Ali.
Joseph Cook Angus.
Charles Ashley Angwin.
Ian Barry.
Victor Bayley.
Eugene Guy Euston Beaumont.
William Chalmers Kirkbride Berrie.
Leonard Shelford Bidwell, B.A. (*Cantab.*)
Richard Warre Bluett.
Frank Kendall Borrow.
James Milne Bowrey.
George Gladman Braid.
George Townshend Brooke.
Denis Robert Howe Browne.
Robert Bruce.
Thomas Cruickshank Bruce, M.A. (*Aberdeen.*)
Ellerington William Buckley.
Frank Bullivant.
John Harold Burman, B.Sc. (*Victoria.*)
Joseph Fawkner Butler.
Colin Stuart Campbell.
Henry Alwyn Close.
Frederick Horton Clough.
Cecil Alfred Colyer.
John Polson Cook.
Walter Gough Cooper.

Students—continued.

Paul Sidney Couldrey, B.Sc. (*Victoria.*)
Herbert Rostron Disley.
Alfred Ernest Drown.
John Reginald Hare Duke.
Edward Gray Faber.
William Robert Field.
Walter Townshend Fletcher.
Chye Tian Fook.
Walter William Ford.
Charles Foard Franks.
Ralph Freeman.
Craven Garnett.
Henry John Garrioch.
William Percival Gauvain.
Bernard Foster German.
George Wynter Gray.
John William Griffith, B.A. (*Dubl.*)
Francis Sylvester Grimston.
Robert Tullis Harrison.
Percy Pedley Harford Hasluck.
John Hammersley Heenan.
Charles Inglis Hutton.
Charles Edward Inglis, B.A. (*Cantab.*)
Victor Mesham James.
Charles Cuthbert Johnson.
Charles Johnston.
Adrian Brookholding Jones.
Gerald Lloyd Jones.
Samuel Carey Jones.
Henry Wingfield King.
Albert Stevenson Laurie.
Charles Ansdell Leech.
Francis Augustus Legge.
Llewellyn Rolls Lester.
Francis Kennedy McClean.
Thomas James McDonald.
Duncan Alexander MacDougall.
Hugh Torquil MacLeod.
Hugh Somerset Margesson.
Thomas Leigh Matthews.
Robert Godfrey Monro, B.A. (*Cantab.*)
Everett William Moore.
Norman Alfred Morcom.
Richard Cecil Moser.
Rustom Kaikhasro Nariman.
Henry Archer Neild.
Hugh Percy Nesham.
Frederic Charles Nissen.
William Henry Nott.
Geoffrey Gream Ommanney.
William Alexander Parker.
Paul Gerhardt Parkinson.
Clifford Copland Paterson.
Charles Edmond Cleaver Peach, B.A. (*Cantab.*)
Percy Charles Penn-Gaskell.
George Ingram de Brissac Phelps, B.A. (*Cantab.*)
John Dudley Plumpton.
Harold Reid.
William Carstairs Reid.
David Rew, B.A. (*Cantab.*)
Alan Reynolds.
James Rickman, B.A. (*Cantab.*)
Arthur Gabriel Madox Rossetti.
Percy Rothera.
Douglas Leslie Serpell.
Eardley Oswald Shields.
Ernest Darwin Simon.
Alfred Robert Sinclair.
Albert Bromley Smith.
Clayton Stallard Sparrow.
Edmund Stone Spencer, B.Sc. (*Victoria.*)
William Henry Stacey.
Reginald Harry Hursthouse Stanger.
Charles Henry Stewart, B.Sc. (*Victoria.*)
George Sunders.
Edward Ernest Tasker.
Frank Coston Taylor, B.A. (*Cantab.*)
Charles Tennant.
Waude Thompson.
Alfred Douglas Tisdall.
Philip Walmesley Tolhurst.
Henry Turner Tovey.
Charles Harold Townsend.
Wynne Harold Tregoning, B.A. (*Cantab.*)
Karl Theodor Berthold Tressler.
Sydney George Turner.
Frederick John Tyley.
Henry Herbert Sydney Upton.
Arthur Vincent Venables.
Osmer Bernard Ward.
John Warrack, B.Sc. (*Glas.*)

Students—continued.

Lionel Fortescue Wells, B.Sc. (*Victoria.*)
Edward Theobald West.
Charles Francis Russell Nugent Weston.
John Stanley Whitaker, B.Sc. (*Victoria.*)
Ernest Charles Winter.
Richard Wood, B.A.I. (*Dubl.*)
Anibal Zamora.

The Candidates balloted for and duly elected were: as

Members.

George Henry Banister.
Leffert Lefferts Buck.
Thomas James Bush.
Charles Cosby Stewart Clark.
William Francis Cotton, Jun.
John Marshall Gorham.
Robert Hammond.
Edward Alfred Harman.
Donald Calder Leitch.
Ambrose James Molloy.
Sir Thomas Salter Pyne, C.S.I.
James Rowan.
Arthur Taylor.
William Steains Vaughan.
James Wallace.

Associate Members.

Henry George Vergottini Adler, Stud. Inst. C.E.
Eliseo Anzorena.
David Williams Armstrong.
Arthur Charles Beard.
Norman Macleod Bell.
Percival Noel Boscawen.
Charles Edward Bremner.
William Alfred Henry Clarry.
Henry William Clothier.
Harvey Collingridge.
Conrad Alan Cooke.
Nicholas Edward Cornish.
Clement Allan Cunnold.
Geoffrey Scott Dalgleish, B.Sc. (*Edin.*), Stud. Inst. C.E.
Arthur Henry Daniel, Stud. Inst. C.E.
James Alfred Grenier Driebberg.
Audley Mervyn Duke, Stud. Inst. C.E.
Kenelm William Edward Edgcumbe, Stud. Inst. C.E.
Frank Furnivall.
Philip John Fitz-Gibbon.
David Gilmour.
Andrew Gray, Stud. Inst. C.E.
Robert Thomas Greer, B.E., LL.B. (*Royal.*)
Conway Osborne Grimshaw.
Frederick Herbert Hare.
Alfred Francis Harley.
Thomas Hayward.
Ashton Marler Heath.
Theodore Rathbone Hubback.
Frank Harvey Hummel, Stud. Inst. C.E.
James Husband.
Arthur Henry Johnstone, B.A.I. (*Dubl.*)
Walter Robert Kay.
Robert Jackson Kent.
William George Kirkaldy.
Cyril Reginald Sutton Kirkpatrick, Stud. Inst. C.E.
Jacob Kraus.
Christian Kussmaul.
William Wright Larmor, B.A. (*Royal.*)
Edward Huntington Leaf, B.A. (*Cantab.*)
Henry Meredith Leaf, B.A. (*Cantab.*)
Henry Cooke Leake, Stud. Inst. C.E.
Samuel McCay, B.E. (*Royal.*)
William Stewart McGregor.
Robert Mansel.
William Mason, B.Sc. (*Victoria.*)
Frank Merricks.
Frank Mills.
Lee Murray, M.C.E. (*Melb.*)

Associate Members—continued.

Charles Herbert Parker.
Samuel Wright Perrott, B.A.I. (*Dubl.*)
William Richard Victor Prittie Perry, B.A.I. (*Dubl.*)
Alan Price, B.A. (*Dubl.*)
Philip Morris Pritchard.
Alexander Cumming Raff.
John Francis Jodrell Reynolds.
Edward Richard Roche, B.A.I. (*Dubl.*)
Harry Oliver Baron Shoubridge, Stud. Inst. C.E.
George Alfred Smith.
William Tom Wood Somers.
James Stirling.
Hubert Townsend Storrs, B.Sc. (*Victoria*), Stud. Inst. C.E.
Leonard Godfrey Pinney Thring, B.A. (*Cantab.*), Stud. Inst. C.E.
Alfred John Wadley.
John William Wainwright.
Louis Heathcote Walter, B.A. (*Cantab.*)
William Wark.
Percival Robert Augustus Willoughby.
Alan Wilson.
Robert MacDonald Wilson.
Thomas John Winn.
Frederic Dickinson Workman, Stud. Inst. C.E.

Associates.

William George Ranger Cordue, *Capt. R.E.*
Frederick Henry Grinlinton.
John Turner Morris, Stud. Inst. C.E.
James Neilson.
Percy Thomas Owen, *Capt. N.S.W. Head Quarters Staff.*
Henry Joshua Phillips.

The discussion on the Paper "The Effect of Subsidence due to Coal-workings upon Bridges and other Structures" was continued and concluded.

Sect. II.—OTHER SELECTED PAPERS

(*Paper No. 3086.*)

"Trial Survey for a Railway over the Outeniqua Mountains, Cape Colony."

By Charles Edward Stewart, Assoc. M. Inst. C.E.

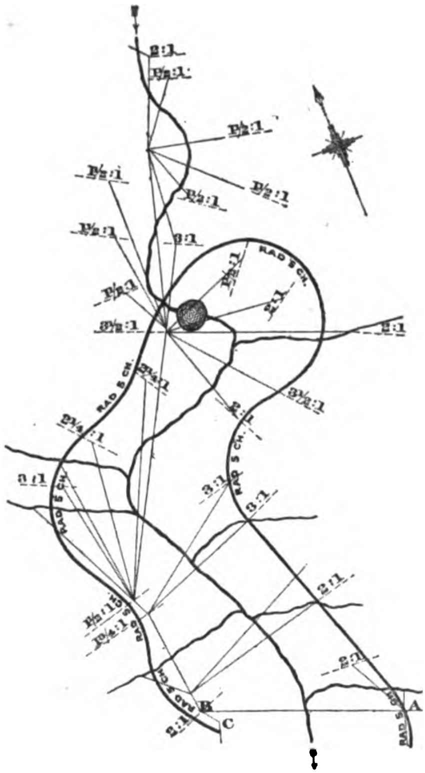
In this Paper is described the trial survey undertaken by the Author to carry an approximate line over the Outeniqua Mountains on the basis of a 1 in 60 gradient and a limiting curvature of 5 chains radius.

To the north of the mountains lies the Oudtshoorn, or second plateau, to the south the George, or coast plateau, and the dividing ridge of Afgunst Neck, through which it is proposed to tunnel, is about 2 miles distant from Montague Pass Neck and 170 feet above it. The summit to be overcome is about 1,400 feet above George. In 1880 a detailed survey, on the basis of a 1 in 40 gradient, was undertaken by the Government for a line of railway over the mountains, passing through the Montague Pass, where a good roadway was constructed in 1844.

The trial survey was commenced at Afgunst Neck; the summit level being fixed at 1,460 feet on the same datum as the Government survey through Montague Pass, giving a total ascent from the point of departure on the Government line at George to a summit of 1,363 feet. A trial line was carried from the summit of the proposed tunnel to ensure a junction with the Government line on the northern slope, the distance being found to be 3 miles 10 chains with a gradient of 1 in 70. The next step in the survey was to derive an accurate section of the proposed tunnel through the dividing ridge. A section of the ridge seemed to present a series of five straight lines, the southern slope being as steep as 1½ to 1. These slopes were measured with a theodolite, the lengths being taken with a tape and the horizontal equivalents were deduced from them. The flying levels were then carried over the ridge and down the south side, and the tunnel was laid out on a gradient of 1 in 60, with a summit of 2 chains of level. The length of the tunnel was calculated to be 720 yards. From the south side of Afgunst Neck the gradient traverse to George was then started by way of the

Kayman River and Zwart River Valleys. The continuous line in the *Figs.* shows the gradient traverse, and the radiating lines level contour points. The side slopes of the mountain and ravines are shown by dotted lines, and the centre-line of the proposed railway by a curved line. The instruments employed for the work were a 14-inch Dumpy level provided with stadia wires, an Abney level, and a prismatic compass. The level was placed over each peg on the gradient traverse, the height of the line of collimation being taken at each peg with a tape and the distance ahead to the next peg with the stadia wires. When practicable all pegs were inserted on the 1 in 60 gradient traverse; and generally between 100 feet and 600 feet distant. Longer sights than 40 feet could not sometimes be taken owing to the undulations of the side slopes of the mountain. The 14-foot levelling staff would not permit of a length of more than 600 feet, as the height of the line of collimation usually exceeded 4 feet. Owing to the rocky nature of the mountain slopes, the ground level was worked to at the pegs and not the tops of the pegs, as it would have been difficult to drive the pegs to any desired level between the clefts of the rocks. The bearing of each peg was taken with a prismatic compass placed on the top of the level tripod, and at each station the level was unscrewed from the tripod for the purpose of replacing the prismatic compass. The transverse inclinations of the ground were taken at each peg with the Abney level; they varied between $1\frac{1}{2}$ to 1 and 7 to 1. The Author was able, with the aid of two men, to carry on these three operations at the same time,

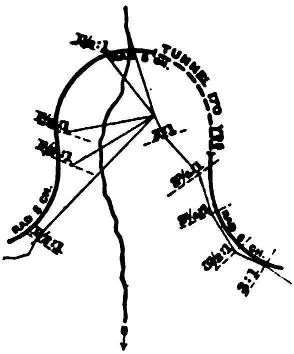
Fig. 1.



Scale, 1 inch = 800 feet.

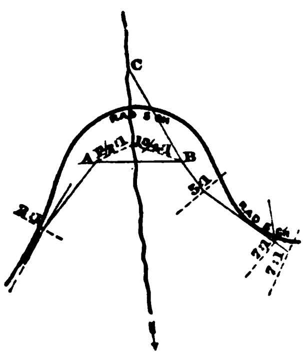
accomplishing on favourable ground as much as 4,700 feet in 1 day. The flying levels were carried on at the same time, as a check on the gradient traverse, and bench-marks were established along the line of the proposed route. The levels usually checked well with the grade line; at times only a difference of 0·30 foot occurred in a distance of about 2 miles. At the last point on the gradient traverse near the junction of the deviation with district No. 2 of Government survey at George there was an accumulated difference between the gradient traverse calculated on the total distance and the flying levels of 7·16 feet. The flying levels closed with the Government datum at George to 1·60 foot. The closing point of the gradient traverse was actually the crossing of Zwart River, as seen by *Fig. 1.* The gradient traverse was continued to the point A, the line AB being taken on the level at a distance of 854 feet. All lines north of AB were taken on the level from the right bank of the stream, a staff-man remaining on each side. The point chosen for the crossing of the Zwart River is immediately above a waterfall 60 feet high. The gradient traverse was again started at C with a fall of 34 feet towards George. The length of the proposed line round the diagram being estimated, the gradient traverse was continued down the Zwart Valley and along the mountain slope north of George. When a junction was made with the Government line at George it was found that the total distance from Afgunst Neck was sufficient to work in a 1 in 60 gradient with 50 chains to spare in length. When the Author started the 1 in 60 grade line from the summit traverse he did not expect to be able to work it in without having recourse to a zigzag on the mountain slopes north of George. The unexpected distance was obtained by the windings along both sides of the ridge of mountains which divides the Kayman River Valley from the Zwart River Valley.

Fig. 2.



Scale, 1 inch = 800 feet.

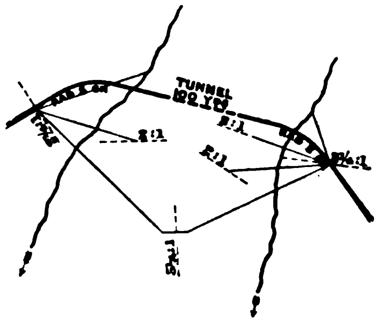
Fig. 3.



Scale, 1 inch = 800 feet.

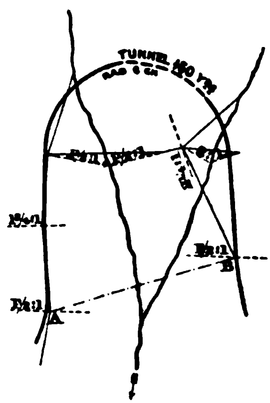
Fig. 2 shows a ravine in Zwart River Valley where, in order to round it, a tunnel 170 yards long had to be introduced. One side of the ravine, as seen by the radiating lines, fits a 5-chain curve well. *Fig. 3* shows a ravine in Zwart River Valley; the line AB is on the gradient and across the ravine. The line BC is a "side shot" and on level, the side slopes of the ravine being $1\frac{1}{2}$ to 1 as shown by dotted lines. The actual slope of the bed of the ravine was found generally to be about half that of the side slopes. It was therefore easy to compute the height of the proposed formation level above the bed of the stream in the ravine. The height at this point was 50 feet, the limit for rock-filling. The amount of rock-cutting at each side of the ravine was adjusted to balance the filling. *Fig. 4* shows a spur in Kayman River Valley where it was necessary to introduce a tunnel 100 yards in length. *Fig. 5* illustrates a ravine in Kayman River Valley at a place locally known as "Charlie's Neck," which is a dividing ridge between the Kayman River Valley and the Zwart River Valley. A topographical plan was prepared some years ago by Mr. Ballott, Government Surveyor, George, proposing to tunnel through this ridge into the Zwart River Valley and from that point follow a gradient of 1 in $41\frac{1}{2}$ to George. This route was examined by the Government and pronounced impracticable.

Fig. 4.



Scale, 1 inch = 800 feet.

Fig. 5.



Scale, 1 inch = 800 feet.

The total curvature was 699 chains; the total length of the proposed route being 19 miles 25 chains. The straight portion of the line will then be 846 chains, or more than half the total length. The limiting straight between contrary curves was taken to be 150 feet. The 5-chain curvature was found to cover 21 chains for each mile of line. The length through Montague Pass, according to the Government survey, is 12 miles 64 chains

from the point of departure of new route to the point of return. This gives an increased length of 6 miles 41 chains in the case of the Kayman Valley route over the Montague Pass route.

The general statement of the curves and straights is as follows:—

5	chains radius, No.	62,	of	404½	chains aggregate.
6	,, ,, ,,	13	,,	88½	,, ,,
7	,, ,, ,,	9	,,	46½	,, ,,
9	,, ,, ,,	6	,,	53	,, ,,
10	,, ,, ,,	14	,,	50½	,, ,,
12	,, ,, ,,	1	,,	17	,, ,,
20	,, ,, ,,	6	,,	17	,, ,,
30	,, ,, ,,	5	,,	20	,, ,,
80	,, ,, ,,	1	,,	2	,, ,,

The total length of line is scaled from the general plan of the gradient traverse, and this agreed fairly well with the distance by the traverse. Between Afgunst Neck and the crossing of the Zwart River the total scaled distance along the proposed centre-line of the railway was 100 feet longer than the traverse distance, although at one point it was 1,450 feet short; but the distance was again made up by additional windings into ravines over the traverse line. On the total distance to George the length found for the proposed centre-line of the railway was 1,685 feet short when compared with the distance by the gradient traverse.

The total length of 1 in 60 gradient is 15 miles 43 chains, all on the southern slope of the mountains. At the crossing of the Zwart River there is a level of 30 chains, and at the summit a level of 2 chains. Between the crossing of the Zwart River and the summit short lengths of 1 in 70 were introduced at points of severe curvature, and only in places where 5-chain curves were more than 10 chains long, the aggregate of such lengths of 1 in 70 gradients being 20 chains. From the summit to the junction with the Government survey on the Northern slope the distance is 3 miles 10 chains, all on a gradient of 1 in 70.

The structures required consist of one viaduct and one bridge. About 1 mile south of the summit a gorge in the mountain was crossed by the gradient traverse. A special section was taken at this place which proved that a viaduct of cantilever type would be required with a central span of 300 feet, and two side spans of 200 feet, with piers 120 feet and 90 feet high respectively, the height at the centre above the stream being 250 feet. A traverse was run into this gorge which proved the impracticability of curving into it. The crossing of the Zwart River is a work of much less importance. An accurate section was taken which

proved that a bridge would be required consisting of one central span of 90 feet and two side spans of 50 feet, with piers 60 feet high. Both these structures were on the straight, and drawings were prepared for them.

In addition to that at the summit there are four tunnels, three of which are shown in the *Figs.* These were necessary owing to the peculiarly cramped formation of the mountain, and without them it would not be possible to fit the line to the mountain side, even with so sharp a limiting curvature as 5 chains radius. The aggregate of these tunnels is 1,320 feet, made up as follows:—Summit tunnel, 720 yards; tunnel at "Charlie's Neck," 150 yards; two tunnels in Kayman Valley, 180 yards and 100 yards respectively; and one 170 yards in the Zwart River Valley, the limiting depth of cutting for tunnel being 50 feet.

From the diagram plan showing the side slopes a trial section was compiled, and from the whole a fairly accurate estimate of the cost was obtained. The estimated cost was increased over the Montague Pass route in proportion to the increased mileage, the general class of work in each case being the same.

The Author carried out the first 9 miles, aided by three men, going into camp early in January, 1897; but at the end of April he was joined by Mr. Ragnar Filén, formerly of the Swedish Government Railways, who rendered him valuable assistance both in the field and in the office. All field and office work was completed by September. The wet weather and mists on the mountain much impeded operations, and the dense bush had to be burnt out before anything could be done. This survey necessitated nine different encampments on the mountain, three of which were not even accessible by bridle-path. With the exception of the first and the last, the camps were moved with the aid of carriers.

The Paper is accompanied by three drawings, from which the Figures in the text have been prepared.

"The Congo Railway."[1]

By Léon Trouet.

(Translated and abstracted by Gilbert Richard Redgrave, Assoc. Inst. C.E.)

Though no official connection exists between Belgium and the Congo Free State, which is absolutely autonomous, there are so many intimate ties between the two countries that everything relating to the vast African territories, under the personal sovereignty of King Leopold, cannot fail to possess a powerful interest for the Belgian people. The Author shows that almost the entire Congo basin is comprised within the limits of the Free State, and that the numerous and important tributaries of the Congo distinguish its watershed from that of almost every other great river. The chief confluents and branches discharge into the broad stretch, known as the Stanley Pool, above which the Congo and its tributaries are navigable for upwards of 11,000 miles. Below Stanley Pool, as far down as Matadi, the river ceases to be navigable, owing to the falls and rapids caused by a descent of about 1,000 feet in a distance of about 217 miles. From Matadi to the coast the river is practicable for vessels of large tonnage, and Matadi is, in fact, the destined port of the Congo basin. It was clear that from every point of view it was a matter of urgent necessity for the sake of the future development of the country to provide means of transport between the Upper Congo and the navigable estuary at Matadi, and thus to do away with the interruption to traffic caused by the impassable rapids. From various considerations it is shown that the construction of a railway afforded the only practicable solution of this difficulty, the canalization of the river being out of the question.

As soon as Mr. H. M. Stanley had opened up the country by his explorations in 1878, the idea of the railway had been mooted, and as early as 1885 a syndicate of English capitalists approached the

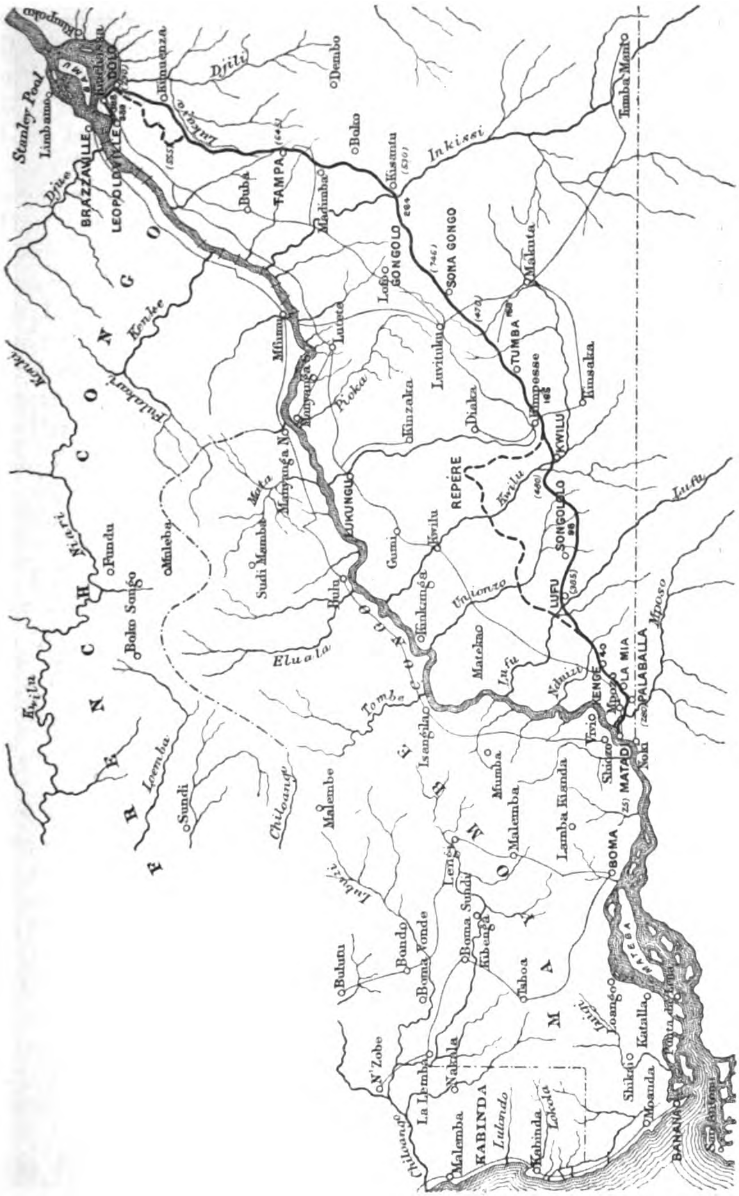
[1] The original article appeared in the *Annales des Travaux Publics de Belgique*, vol. iii. (2nd series), 1898, pp. 575–675.

Congo Free State with a view to a concession for the construction of a railway from the Lower Congo to Stanley Pool. Affairs were, however, at that time hardly sufficiently advanced for the realization of this project, but shortly afterwards a Belgian Company was formed, with the modest capital of £50,000 (originally £40,000), to prepare the way for a more complete study of the question. This company was definitely launched on the 9th February, 1887, as the "Congo Company for Commerce and Industry," and the first step taken was to despatch two expeditions, the one to seek out and to survey the best route for the proposed railway between Matadi and Leopoldville, and the other to report upon the commercial prospects in the future of the basin of the Upper Congo. The first of these expeditions, the survey party, was in charge of Captain Cambier, who had already, on two previous occasions, travelled in Africa, and the second party was entrusted to the leadership of Mr. Delcommune, who had for 12 years been engaged in commercial pursuits on the Upper Congo. Captain Thys was at the same time appointed to proceed to Africa and to take charge of the two enterprises as the chief representative of the Company.

Some previous proposals, namely, that of Stanley for a railway from Vivi to Isangila, following the north bank of the Congo, and a scheme for a similar line from opposite points south of the river are noticed. Both of these lines would have terminated at Isangila, where a stretch of the Congo is navigable for whale-boats, skilfully managed by native oarsmen, as far up as Manyanga. From this point, a second railway would have carried the traffic to Stanley Pool. There had been also a projected line from Matadi to Stanley Pool direct, without break. The two former schemes, though they would perhaps have been less costly in point of execution, were open to grave objections, owing to the necessity for several transhipments and the great difficulties in the navigation above Isangila. The Company decided, therefore, to attempt to construct a railway direct from Matadi to Stanley Pool. At the period of the inception of the scheme, the country between these two points was wholly unexplored, but for the two caravan routes, the one to the north of the Congo, and the other to the south. The latter seemed to offer the fewest difficulties for the construction of the railway, and the survey party, which started in 1887 and returned in 1889, adopted this route. The conditions laid down for the railway were as follows:—The gauge was to be 29½ inches; the maximum gradients 45 feet per 1,000; minimum radius of curves 2½ chains, while tunnels and all heavy works were to be as

far as possible avoided. In order to save time and to reduce the preliminary expenses, the engineers were only called upon to furnish an approximate scheme, showing the possibility of constructing the line and enabling them to estimate the probable outlay. The difficulties encountered were, with three exceptions, readily overcome; these were (1) the section skirting the torrential stream, the M'Poso; (2) scaling the heights of Palaballa, which rise precipitously directly after that river is passed; this proved the most knotty point of the scheme; (3) in attempting to reach the Pool by the most direct route, the surveyors entered the valley of the Lukunga, a tributary of the Congo, the opposite bank of which presented a cliff-wall which was absolutely impassable and which attained in places a height of upwards of 3,000 feet. It was, in fact, an invincible obstacle, which appeared for a time likely to destroy all their hopes of success, since this rock-wall was found to follow the whole course of the river to its junction with the Congo, and thus constituted the separation between the basin of the Lukunga and that of the Congo. The only alternative open to them was to ascend the course of the river Lukunga, without, however, much anticipation of finding an outlet, since the general direction of all the tributaries on the left bank of the Congo was such as to cause them to conclude that it would speedily lead them into Portuguese territory, which was near at hand. By a lucky circumstance it was found, after following up the valley for from 12 miles to 15 miles, that the stream, in lieu of trending due southward, made a sharp bend to the north-east, encircling the precipitous cliffs on the right bank, which are only terminated northwards by the Congo itself. The survey line was, therefore, taken up the valley, and only diverted later to strike off towards the Stanley Pool, which was reached after crossing the Inkissi, the most important river which had to be traversed, and passing over the Tampa Plateau, the highest ridge of the chain of mountains encircling the central Congo basin. By means of a map (*Fig. 1*) of the Congo State, the Author explains the original route proposed and certain modifications, which were introduced during the execution of the work, with a view of shortening the distance and reducing the cost. The length of the line, as originally surveyed, was 285 miles, but the ultimate length is 241 miles. Some of the principal elevations above datum are as follows:—Matadi, at the starting-point, 86·6 feet; ridge of Palaballa, 918·6 feet; ridge of Zolé, 1,574·8 feet; ridge of Sona-Gongo, 2,444·2 feet (summit-level of line); ridge of Tampa, 2,083·3 feet; Plain of Stanley Pool, 1,033·4 feet.

Fig. 1.


Stanley Pool
BRAZZAVILLE
LEOPOLDVILLE
DOLO
Kimuenza
Djili
Dembo
Lukaya
TAMPA
Buba
Boko
Kisantu
Inkissi
Tumba Mani
GONGOLO
SONA GONGO
Madimba
Makuta
TUMBA
Luvituku
Kimpesse
Diaka
Kinzaka
Kimsaka
KWILU
REPERE
SONGOLOLO
Lufu
LUFU
Mfumu
Lukunga
Manyanga N.
Mata
LUKUNGU
Sudi Mamba
Gumi
Kwilu
Buba
Kinkanga
Vallonzo
Eluala
Tomba
Isangila
Mateko
KENGE
LA MIA
PALABALLA
Mposo
Vivi
MATADI
Noki
Shiolo
Lamba Kianda
Mumba
Malemba
BOMA
MATEBA
Loango
Katalla
Punta da Lenha
Shiloango
Moanda
BANANA
San Antonio
KABINDA
Lulondo
Lokolo
Kabinda
Malemba
La Lemba
Nakala
N'Zobe
Bulutu
Bondo
Boma Vonde
Boma Sundi
Kibenga
Taboa
Lengi
Lubuzi
Chiloango
Malembe
Sundi
Loemba
Kwilu
Boko Songo
Fundu
Niari
Maleba
Kenkee
Djue
Kimpoko
Limbamu
F R E N C H   C O N G O
M A Y O M B E

In consequence of the absence of all navigable streams and of every mode of transport except by negro carriers, it was necessary to adopt what is here termed the "Telescopic" system, for the construction of the line; that is to say, that the railway itself had to provide all the materials for its extension, by means of the section already constructed, and all fresh supplies had to be pushed forward from the base. Even the workers themselves had to be recruited and lodged and fed by the Company, in special camps constructed as the works proceeded, for the country in the region of the cataracts is very sparsely inhabited, and it was at all times impossible to advance more than from 7 miles to 9 miles beyond the end of the rails. It may readily be imagined that vast difficulties had to be overcome in thus constructing a railway in an unknown country with wholly unskilled workers, who had never seen a pick or a shovel, under climatic conditions, moreover, of the most unfavourable kind. Still for several years the railway was pushed forward at the rate of from 60 miles to 72 miles annually, and although critics, who were not familiar with the real circumstances of the case, have been disposed to cavil at certain of the details, all those who have studied the railway on the spot have been enthusiastic in their praises of the undertaking.

As soon as the works were actually taken in hand, the preliminary survey was only looked upon as furnishing a general idea of the line to be followed, and any possible improvements which became apparent as the railway proceeded were invariably adopted. From the 56th mile onwards it was decided to reduce the maximum gradients from 45 per 1,000 to 40 per 1,000, and to increase the radius of the curves to a minimum of 3 chains.

The surveying party in advance of the excavators, who went forward to stake out the centre of the line and to drive in posts to mark the levels of the formation, had to see that the grass was cut down, for otherwise this constituted an almost impenetrable jungle, attaining during the rainy season to a height of from 10 feet to even 20 feet. They had also to construct light foot-bridges over the streams and ravines to permit of the passage to and fro of the workpeople, and lastly they had to select and prepare the spots chosen for the camping-grounds. The soil in the regions traversed by the railway is very varied in character, but little hard rock was encountered until Palaballa (10 miles) was passed. Towards the 140th mile there exists some rocky ground of intense hardness, which had to be blasted with dynamite. Though much of the ground was very firm, it yielded readily to the pick, but some beds of tough clay were found which crumbled on exposure

to rain and to the atmosphere. Very few of the cuttings were made in vegetable soil, as the line followed for the most part the spurs of the hills, denuded by tropical rains. A photograph of one of the deep cuttings is given, to show the nature of the excavations. Along the banks of the Congo and the M'Poso, that is to say, for the first 5 miles, the construction of the railway on the face of the rocky cliffs was a work of much difficulty and even danger, and the workmen had in some cases to be slung from above by means of ropes. The line in these places follows the bed of the torrent in a species of semi-tunnel formed in the rocks at a height of from 130 feet to 160 feet above the stream, the mere elevation causing giddiness to those unaccustomed to similar scenes. It was necessary also in some instances to build up lofty foundation walls from below to carry the line which projects beyond the face of the cliffs.

The picks and shovels used by the negro workers were of the usual make, but somewhat smaller in size than those generally employed. Small barrows with cast steel wheels were made use of in the cuttings, and in certain of the deeper and longer excavations and embankments iron tip-wagons, holding about 9 cubic feet and running on a portable rail with a gauge of 16 inches, were introduced with success. The individual work done by the negro excavators was at first very small, but it improved ultimately up to 3½ cubic yards per diem, mainly under a system of premium payments founded on piece-work. The Author recommends this system for all work of a similar character, whatever may be the race of workpeople employed. In connection with the excavators' work two special gangs were employed, the one charged with the preparations for the bridges over the ravines and rivers, and the other having to deal with the construction of the metallic culverts and the trimming of the embankments. Rough timber trestle-bridges of given dimensions were in the first instance erected, and it may seem strange that, in a country which abounded with forests, it was found cheaper to employ imported European wood than to prepare squared timber on the spot. A photograph shows the character of the trestle-bridges adopted. With respect to the metallic culverts, it is stated that these no doubt constituted one of the chief factors in the possibility of speedily constructing the railway. As a matter of fact, though the bridges are fairly plentiful on this line, the small watercourses and channels may be said to be innumerable, and as in every case it was necessary to confine and train the waterways, the use of a multitude of small culverts (aqueducts) under the line was unavoidable. Masonry in

Africa is very dear, and the negroes are very slow in constructing arches and vaults. If all the culverts under the line had been built in stonework, it would have been impossible to attain to any great rapidity in completing the railway. It was originally proposed to carry out these culverts in compressed concrete, but the cost for freight was excessive. It was found also after a short trial that concrete castings were not strong enough to stand the rough handling during the voyage from Europe, and that a very small fraction of the consignment arrived at the works intact. Under these circumstances it was resolved to make use of steel tubes, which were supplied in two dimensions, the smaller 19·7 inches in diameter, in lengths of 23·6 inches, and the larger 39·3 inches in diameter, in lengths of 31·5 inches. These tubes were formed of mild sheet-steel, varying in thickness from 0·15 inch to 0·35 inch. They were riveted together and made to taper slightly, and the sizes were so adjusted that three lengths always fitted one within the other, for the sake of saving in freight. Each end is fitted with a hoop, to ensure a good joint, and at first the tubes were jointed with Portland cement; subsequently joints of tow and red lead were used instead, but latterly all jointing has been dispensed with, as the earth soon washes into the interstices between the tubes and becomes consolidated. The Author shows that the objections as to want of durability urged against this mode of forming the culverts have not been established in practice.

Although the gauge was first fixed at 29·5 inches, the rails as actually laid have a gauge of 30·1 inches. This small widening was decided upon as being that required for the maximum curvature. The line abounds with sharp curves, involving constant slight changes of gauge, and as it would have been difficult to avoid errors in the dimensions, it was ultimately decided to adopt the above extended standard gauge throughout. The rails weigh 43·4 lbs. per yard, and were supplied in lengths of 23 feet to suit the trucks. Some shorter lengths were furnished to serve for the inner rails on curves of 2½ chains. A Table is given of the elevation of the outer rail for curves of various radii, calculated for a normal speed of 18·6 miles per hour, these elevations varying from 2 inches on a curve of 2½ chains down to 0·2 inch on a curve of 25 chains.

Two descriptions of fish-plates were at first used, flat-plates and angle-plates, but the former were soon given up, because they were found unfitted to stand the heavy strain on the curves. All but the first few miles of rails are therefore jointed by means of double angle-fish-plates. The rails are of semi-mild steel, the

fish-plates of mild steel, and the bolts of iron. The sleepers are of the "Ponsard" type, of rolled mild steel, weighing 71½ lbs. each, and they receive while hot a coating of tar. They can be handled by one man, and can be laid very rapidly. The rails are fixed to the sleepers by two tee-headed bolts, screwed into a binding-plate beneath. They rest on wedge-shaped bearing-plates, riveted to the sleepers, giving the rails an inward cant.

The stores sent up on trucks from Matadi were unloaded at temporary depot-wharves near the rail-end, and moved forward from time to time as the work advanced. The locomotives employed while the line was being constructed were of the type known as "works engines," of the same description as those used for haulage before the ballast was laid. Special patterns of points, crossings, and switches were employed, which were made in three pieces in Europe, and were very rapidly put together where required in less than an hour each. All crossings are of one uniform angle, 7° 45′, and the points are 8 feet 2 inches in length. The sidings signals are simple disks of the usual pattern, placed at from 220 yards to 330 yards from the sidings, and controlled by levers of the ordinary type. The water-towers, of a capacity of 2,200 gallons, are situated at convenient distances apart, and possess in each case a water-crane attached to them. The supply to the towers is by means of hand-pumps of the "Californian" type. Attempts are being made to provide for water in larger quantities, and the use of windmill pumps is proposed. Over parts of the line in certain seasons it was difficult to obtain water, and to overcome this drawback three tenders were constructed, each capable of carrying 660 gallons. They were made of a special pattern, so as to serve at the same time as wagons, but so far they have not been used.

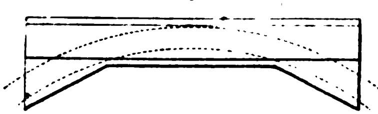
All the masonry employed was of the nature of rubble-work, squared stone not being available. Slaked Tournai lime and cement were brought from Europe, and the sand was procured from the beds of the torrents. The mortar consisted of two parts of lime, one part of cement, and three parts of sand. This mixture was very rich, but the importance of strength was permitted to outweigh the question of economy.

Whatever might be the span of the bridges, the chief consideration was the need of avoiding intermediate piers, owing to the torrential character of the streams. Only two of the bridges contain more than one span, the one having a clear width of 229·6 feet, and the other of 196·8 feet. In these cases no other course was open, because it was found after the ironwork had

been constructed that the waterway was insufficient, and that in both cases an extra span of 65·6 feet was needed.

Very few difficulties were encountered in the construction of the masonry for the abutments, as this work could generally be executed in dry ravines. In crossing certain rivers and marshes, however, the water present involved rather heavy hand-pumping. The breast-walls of the metallic culverts were constructed in 18-inch rubble masonry, built up flush with the ends of the tubes. In some instances, when the volume of water to be dealt with was large, three or more of the metal tubes were laid side by side and even one above the other, so as to give a sufficient area of outlet, both in width and depth. In these cases the breast-wall was of course made to enclose the ends of the entire group of culverts. In order to provide means for building the abutments of the bridges the rows of piles were so arranged as not to interfere with the work, and the temporary bridges were so constructed as to leave a free space between the piling for the stonework. As soon as the abutments were finished all that remained was to bring forward and fix the iron superstructure. Only cast steel and mild steel were employed in the bridge-work. In the first 180·8 miles, there are in all 110 bridges, which vary in span from 328 feet down to 13·1 feet. The bridges first erected were riveted together in the usual way, but this process proved so defective, so costly and so exceedingly slow, when executed by negro riveters, who were novices at the work, that in all the later ironwork recourse was had to turned bolts, which succeeded extremely well. The bolts were made in a special way by machine, and the Author states that the results in actual practice by the use of bolts were better than those obtained by means of riveting.

Fig. 2.



Many of the bridges are on very steep gradients, and in one case not only was the gradient 1 in 35½, but the line was on a curve of 2½ chains radius. The span of this bridge was 131·23 feet. The Author describes and illustrates by means of a diagram, *Fig. 2,* the special method of construction adopted in the case of this unusual bridge. The lattice-work on the outer side of the curve is straight, but on the concave face the girder is spread out at an angle towards each end and thus bears on to the abutments obliquely, the centre part of the lattice-work remaining parallel to the outer girder. In order to secure the gradient of 1 in 35½,

the top flange, or roadway, finishes at this inclination, while the bottom of the girder is made level to avoid the danger of shifting downwards on the abutments—the girder is thus trapezoid in form. Certain special features in the construction of other bridges are described in detail by the Author. In all cases the design of the ironwork was made as graceful as was possible without entailing any pecuniary sacrifices. Certain of the cast-steel bed-plates for the bridges were too large to be made in one single piece, and had to be joined together *in situ* by key-pieces bolted on. All the superstructures of the bridges up to 40 feet in length were put together in Matadi and loaded there on trucks. The larger bridges were erected in close proximity to the line, and were rolled into position on to the abutments on Sunday mornings when the traffic was stopped for the purpose. Some of the largest spans were put together on their own abutments, the traffic being only interrupted during the time needed to place the transverse joists and rails. Special precautions were taken to guard against the expansion due to the high temperatures encountered, both in the case of the bridge-work and in the method of jointing the rails.

The placing of the ballast was executed as speedily as possible after the rails were laid, though this work was generally 15 to 18 miles behind the rail-head. Materials suitable for ballast were found in more or less abundance all along the line. White quartz pebbles, which are plentiful in the upper layers of the soil in certain districts traversed, were chiefly used. It was found unnecessary to sift the soil containing the pebbles, as it was soon cleansed by the first heavy rains. Beyond the Inkissi the soil is mainly sandy and it was thought unsuited for metalling, but on trial the sand as used for ballast has turned out very well. It is found to be fairly cohesive, it is not washed away nor blown away by the wind and by passing trains, and it keeps well to the trimmed surface.

Having so far described the construction of the line, the Author proceeds to deal with the proposed mode of working the traffic and with the accessory details. First as to the means of transport, which vary in accordance with the particular phase reached in the progress of the work. In the section of the line actually completed for traffic, as far, namely, as the Inkissi, or 164 miles, as also in the section which is completely ballasted, the transport is provided for by the management staff (*service de l'exploitation*). Beyond the section where the ballast ends and where the metals only are laid, the traffic is still under the charge of the ballasting department. The trucks, laden with the materials and with the

food for the workpeople, are all conveyed to the temporary depôt in the proximity of the rail-head. From this depôt all the stores, tools, materials used in the camps, &c., have to be carried forward by the ballasting department. They are consigned to a special agent to whom they are entrusted, and who causes them to be transported to the temporary stores situated where they are actually required for use. Small boxes, cases of dried fish, sacks of rice, &c., not exceeding 66 lbs. in weight are carried by porters; barrels, and iron tubes for aqueducts, are rolled along the temporary way. The depôt stores are very lightly constructed in galvanized corrugated iron. They are each of them 39 feet long by 13 feet wide.

For purposes of communication along the line and in order to regulate the despatch of trains, the company has established a telephone service, the terminus of which is the most advanced point reached by the earthworks. The telephone wire is of oxydized phosphor-bronze, in order not to excite the cupidity of the natives, who have a great admiration for copper. This wire is supported by means of metal standards 16·4 feet in height, with a spiked end from 2 to 3 feet deep in the ground. The posts at first used were of drawn barrel-tubing; but subsequently T-section posts in soft steel, of a weight of 22 lbs. per yard, have been substituted for them with advantage. These posts are fixed from 110 to 165 yards apart. The telephone stations are usually from 12 to 15 miles apart. Some curious interruptions in the service, supposed to be due to the induction of momentary terrestrial currents, which occur during the hottest part of the rainy season, are noticed. The telephone posts are also used to carry a telegraph wire joining Boma and Matadi with the furthest point reached by the railway.

Passing on to the question of the method in which the traffic of the line will be dealt with when the works are finally completed, the Author states that it is proposed to divide the entire length into three sections about equal in length, say each of 80 miles. These will be worked separately, and at the end of each section there will be a change of engines. Stores and workshops will be constructed at each stopping place. As long as no night trains are run the goods trains will cover only one section in the day and the entire journey will thus need three days. Certain passenger trains will complete the journey in two days, and for these there will be a change of engines midway, where engine-sheds and workshops have also been constructed. The stoppage for the night is arranged for at Tumba, at the 116th mile, and here hotel

accommodation has been provided by private enterprise. The traffic will be worked on the block system. A train on reaching a siding will have to await a telephonic message from the signal station beyond giving "line clear." In order to avoid as far as possible the danger caused by the fact that telephonic communication leaves no trace in case of accidents, and with the view to fix responsibility, a very perfect system of booking all the messages has been devised.

Since the railway was projected the progress of trade has been far beyond expectation. In the first instance the tariff rates were fixed very high. All merchandise carried upwards was charged for at the rate of 3*s*. per ton per mile. The only exception made was in the case of salt, which was to be conveyed at half rates. Since these rates were fixed the company has agreed to carry all vessels, steam-engines, mechanical appliances used in agriculture or in industry, as also all electrical and telephonic apparatus, at a reduction of 40 per cent. By a still later arrangement it has been agreed to convey all railway plant for new lines communicating with the Upper Congo above Stanley Pool at half rates.

In the case of the downward traffic differential rates dependent upon the value of the products have been agreed upon, with a view of promoting the export trade. Palm-kernels, ground-nuts and timber pay the lowest rates, about 4*d*. per ton per mile, and ivory the highest, 3*s*. per ton per mile. White travellers pay 1*s*. 6*d*. per mile, and negroes travel at one-tenth this rate. Return fares are calculated at one and a half times the rate for a single journey. First-class passengers are allowed 220 lbs. of luggage free, and second-class passengers, 44 lbs. Thirty or more negroes travelling together in parties, in the service of a white employer, are carried at half fares.

During the construction of the line the maintenance and repairs of the finished section are entrusted to the service which corresponds to the permanent-way department (*voies et travaux*) on European lines; but the section still incomplete is in charge of the construction department. The whole line is divided into sections and sub-sections for the purpose of repairs, each of which is entrusted to a group of native workmen under a black foreman. Each section of about 62 miles has a works engine and a stock of trucks for ballasting purposes. There will eventually be four sets of repairing-sheds, the two chief ones at either end of the line, and two smaller ones at the sectional stations where the engines are changed.

A detailed account is given of the repairing shops at Matadi,

and of the supply of machine-tools, &c. Two types of goods-engines are in use, and after careful study by experts in Belgium a locomotive was specially designed to meet all the exigencies of the case, and adapted for the sharp curves and heavy gradients. The engine in question has eight wheels, the three front pairs coupled with a wheel-base of 7·32 feet, and the axle of the trailing-wheels placed far back, 6·56 feet behind the front group. The total wheel-base of 13·94 feet being quite out of the question on curves of 2½ chains, the trailing-axle is given a transverse movement by the employment of radial axle-boxes, and in addition to this provision is made for a slight amount of play in the leading-axle. This locomotive, like all the later ones, was furnished with a tender. The total weight when empty is 24 tons, and 31 tons when in running order. The boiler is in mild steel, tested to 180 lbs. per square inch; it has a copper fire-box and brass tubes. This engine can propel three 10-ton trucks on rising gradients of 1 in 22. It has great stability, but has not proved well adapted for the sharp curves. This type has, therefore, been given up in favour of a locomotive having six coupled wheels on a wheel-base of 11·8 feet. This engine weighs 21½ tons empty, and 26½ tons in running order, and can take four 10-ton trucks up the steepest gradients on the line. A much lighter engine has been designed for the passenger traffic, having only four wheels coupled on a wheel-base of 6·56 feet, and capable of drawing two carriages, or a carriage and a goods-truck. The passenger engine weighs 16 tons when empty, or 18½ tons in running order. A still smaller engine is used for works purposes. Illustrations are given of each form of engine, as also of the 10-ton trucks on bogies. Some account follows of the coaches and rolling-stock and of the staff in charge of the trains.

Mention has from time to time been made of the rivers and torrents traversed, and it will naturally appear probable that some attempt should be made to utilize the water-power for the generation of electricity. The river Congo at Matadi could easily be made to furnish 250,000 HP., and if three trains were despatched daily over the whole line each way, it would only involve the expenditure of about 2,000 HP. No doubt the practical difficulties in the way of obtaining the power from the Congo would be enormous. It is shown, however, that even if the power could only be utilized within a radius of, say, 37 to 43 miles, the rivers M'Poso, Lufu, Kwilu, Inkissi, and Lukaya would furnish ample power for the sections of the line in their vicinity. For this purpose the rivers in question would have to be dammed, and

expensive works would be needed; but the Author states that none of them would present any special features of difficulty in point of construction, and this question will ere long be seriously considered. In conclusion, the following matters, not strictly relating to the railway, are discussed—the Ports of Matadi and Stanley Pool, the staff of the company, and the financial considerations, together with the mode in which the capital needed for the enterprise has been obtained. The actual capital is £1,200,000, but in addition to this there is a debenture debt of £1,400,000.

Numerous photographs are given of the country traversed and of different parts of the line, and maps are appended of the Congo basin and of the route selected for the railway. One of the maps has been reproduced in the present abstract.

(*Paper No. 3088.*)

"The Erection of a Steel Viaduct upon the Highland Railway."

By HENRY THOMAS WHITE, Assoc. M. Inst. C.E.

IN the design of steel girder-bridges, viaducts, and roofs, as well as in their construction, it is most important to keep distinctly in view the process by which the structure is ultimately to be erected; for the actual work of erecting such framed structures will often be attended with considerable difficulties, demanding as much attention from the engineer as any other matters involved in the general problem of bridge-construction.

The method that may be chosen for the erection of any structure will depend entirely upon its situation and upon the various facilities for getting the material to the site. It may be that one or other of the ordinary processes will be eligible; otherwise, as not infrequently occurs, some special arrangements must be devised to meet the exigencies of a particular case. When the method of erection has been decided upon, it must be carefully considered, whether it does not involve some special arrangement of parts in the general design of the structure; and it will also determine how far the structure may be riveted together in the maker's yard, and what must be left to be done at the site. The Author is of opinion that a fuller acquaintance on the part of the designer with the peculiar facilities or difficulties attaching to the site of the structure upon which he is engaged, and the method of erection, which is determined thereby, would frequently save unnecessary labour and would conduce to better construction.

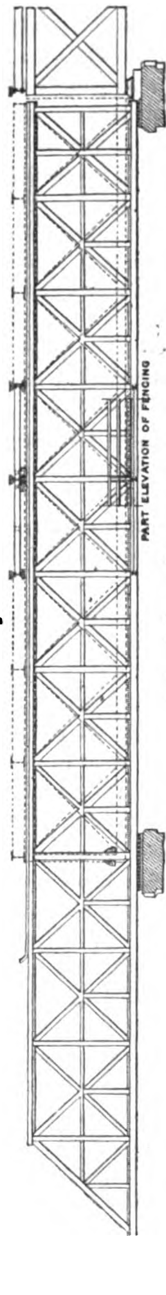
In the present Paper, as a contribution to the subject, the Author proposes to give a description of the method which was successfully employed upon the erection of a viaduct upon the Highland Railway in a situation that called for the employment of special appliances.

The viaduct forms part of the new direct line from Aviemore to Inverness, and carries the railway across the valley of the

River Findhorn in nine spans of 130 feet each, measured between the centres of the piers. The steel superstructure of each span consists of a pair of independent girders of uniform depth, placed 16 feet apart from centre to centre, and carrying the railway upon an upper deck, by means of cross-girders attached to the upper booms. The main girders are supported upon piers of granite masonry, whose height varies with the contour of the valley, the highest being 118 feet from ground-level to the bearings of the girders. The viaduct is built upon a curve of 40 chains radius, and upon a gradient of 1 in 60.

For various reasons it was not considered practicable in this case to erect the superstructure either by lifting the girders from the ground, or by the alternate plan of launching them across the piers from the embankment at each end, as either plan would be attended with great difficulties, and therefore some other scheme was necessary. The method that was devised was that of providing a long bridge-like structure, or travelling stage, composed of steel and timber, which was put together upon the approach-embankment at one end of the viaduct, and was then pushed across the viaduct span after span, the girders of each span being built upon it and left in their final positions, when the stage travelled forward to the next span. The total length of this travelling-stage was 193 feet, measured on the bottom boom, and it consisted of two main trusses, 18 feet deep, braced together at the top and bottom by timber transoms and steel rods. The main trusses, *Fig. 1*, were of a simple type, and were made of a skeleton of steel bars. These bars are flitched on each side with timber in every member, which, under any condition, can act as a strut, while the

Fig. 1.



Scale, 1 inch = 32 feet.

GENERAL ELEVATION OF THE STAGING.

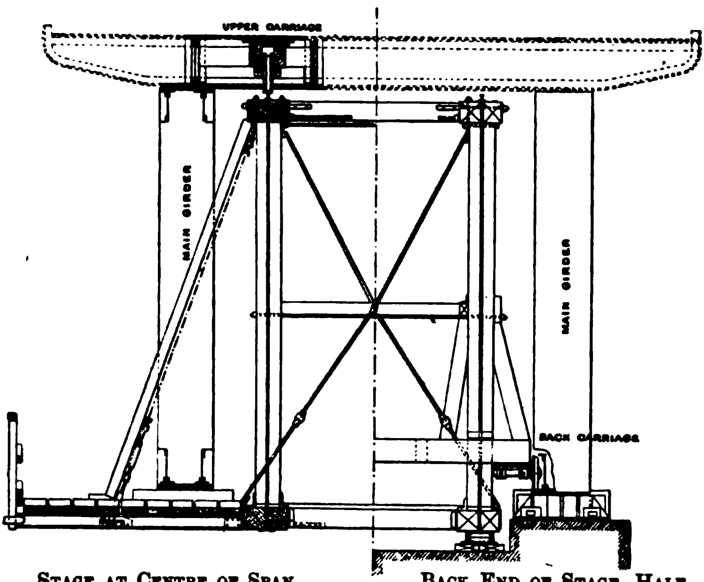
verticals, which can only act as struts, are wholly of timber and have no steel bar. At the bottom of each vertical, folding-wedges were provided, so that the vertical could be tightened to take out any permanent deflection of the stage. On each side of the steel bar, in the bottom booms, an angle-bar was riveted, which, besides supplying a sufficient area of metal to take up the tension in the boom, acted as a path upon which the stage was rolled forward.

The steel skeleton was riveted together, and the timber was carefully fitted on to it, recesses being cut in the timber to receive the rivet-heads. The timber, which varied in section from 12 inches by 12 inches, and 10 inches by 10 inches in the booms to 12 inches by 6 inches and 10 inches by 4 inches in the vertical struts, was bolted to the steel skeleton with bolts passing through both timbers. The small intermediate struts, shown in *Fig. 1*, do not form part of the web-system of the truss, but were placed there merely to strengthen the bottom boom, when it had to act as a beam as the stage travelled over the rollers on which it moved. The main trusses of the stage were placed 9 feet apart, from centre to centre, and were connected at the top and bottom by horizontal systems of bracings, consisting of timber transoms framed across between the trusses at the head and foot of each vertical, and diagonal steel rods with screw connections; while the stage was further stiffened by bracing in the transverse plane, consisting of diagonal rods applied at each vertical of the truss, as shown in *Fig. 2*, and provided with adjustable screw couplings. Being thus braced in every direction, the stage was exceedingly rigid, which was very necessary, as it had to withstand, besides its vertical loads, a very strong lateral wind-pressure. At the back end, and again at a point 130 feet from that end, that is, the bearing point on the next pier, the stage was stiffened with diagonal struts, and special beams were fixed across it horizontally, by which it could be lifted by means of hydraulic jacks whenever it was necessary to insert or remove the rollers from underneath it. The main body of the stage, constructed as above described, was capable of travelling forward telescopically between the erected steel girders of any one span, so as to form a temporary bridge across the next opening; but, before commencing the erection of a pair of girders, the stage was extended laterally by attaching to it, on each side, a movable platform, as shown in *Fig. 2.*

Rolled-steel joists (6 inches by 3 inches in section), projecting from the stage on each side opposite each vertical, were attached to the lower boom by straps, which passed through and took a

bearing upon a steel plate, bolted to the outside of the lower boom of the stage. The joists were held in place by a pin passing through the strap at the back of the plate, and were supported by a 1¼-inch diameter chain, fastened to the upper boom of the truss by a strap-bolt passing through it, and attached to the joist by links and a pin. In each chain was a strong union-screw, by means of which the joist could be levelled when in position. The joists, which were 16 feet apart, were connected by light rods attached to their centres, which served to keep them parallel and

Fig. 2.



STAGE AT CENTRE OF SPAN, HALF CROSS SECTION.

BACK END OF STAGE, HALF ELEVATION.

Scale, ¼ inch = 1 foot.

square with the stage, the last joist at each end being braced to the bottom boom of the stage by a chain and union-screw. On the joists were placed planks 4 inches thick, and on the outside was a strong hand-rail, supported by posts which were fitted into sockets at the ends of the joists. This formed a good and secure platform and on this the girders were built.

The materials were brought to the work upon the earthen embankment which formed the approach to one end of the viaduct, and upon this embankment the travelling stage had to be put together. The steel skeleton of each truss was built and riveted

lying upon its flat, and then the timber was bolted on. When this was finished, the completed truss was turned up on edge, by means of five derricks attached to it at intervals along the top boom. The second truss was treated similarly, and after the cross and diagonal bracing had been put in, the stage was ready for launching.

For launching the stage, rollers were put under each truss in two places. These rollers were 4 inches in diameter, and were made in sets of eight, fixed in a steel frame; two sets, that is, sixteen rollers, were placed end to end, affording a bearing 9 feet in length at each of the four points of support. The rollers were set in their frames to the gradient of 1 in 60, in order that the frames could be bedded level.

The clear span between the piers was 120 feet, and the length of the stage was 193 feet, so that when the stage was pushed forward from the abutment across the first span there would be 73 feet of the stage on the bank to serve as a counterbalancing arm at the moment when the forward point of the stage was just landing on the first pier. It should have been mentioned that the first 130 feet of the stage was made without any camber at all, but the 63 feet at the point had 6 inches of camber, to compensate for the deflection which would occur when the whole 120 feet between the piers was overhanging without support. When the building of the stage was completed and the rollers were put under it, the rear end was loaded with about 40 tons of kentledge to prevent the forward end from overbalancing, and the whole was launched forward by means of hand-winches and block-tackle till the forward end was over the first pier. This end was then temporarily packed up off the pier (the end of the stage arrived usually about 1 foot 6 inches above the pier), and then the rollers, which had been used at the rear end, were taken across and were fixed under the point on the first pier. The launching was then continued till the back 130 feet length of the stage bridged the first span of the viaduct and the forward 63 feet was overhanging into the second span. This was the final position of the stage for the building of the first span of the viaduct. The weight of the stage, when stripped of its side platforms and all encumbrances, was about 84 tons, which, with the 40 tons of kentledge, made a total load of 124 tons, which had to be moved across the first span.

The stage being in position across the span, it was lifted at each end and flat plates were inserted between the rollers and the angle bars which formed the roller-path on the stage, in order to prevent abrasion of the rollers. The platforms were then

fixed on each side of the stage to receive the steelwork of the girders.

For building the girders a hand-crane was provided, which travelled upon rails on the top of the stage. The lower booms were first laid down upon slack-blocks lying upon the planking of the side platforms, and then the remaining members of the girders were built in the ordinary way. This part of the work calls for no especial remark, except that two points had to be noted: firstly, a considerable excess of camber had to be put in the bottom booms when first laid down, in order to allow for the ever-increasing deflection of the stage as weight was added to it; thus, although 1½ inch was the camber specified for the girders when finished and under full permanent load, it was found necessary to put in 3½ inches when first laying the booms down. The second point to be observed was that the stage had to be loaded as equally as possible upon each side-platform; that is to say, that as soon as one member had been fixed on one side, the corresponding member was fixed upon the opposite side. The total weight of each girder was 45 tons. The maximum deflection noted in the stage was about 2 inches, and a large part of this remained after the weight of the girders had been taken off. It was, however, always found possible to get rid of this permanent deflection by tightening the wedges under the vertical struts of the stage.

As soon as the cross-girders and rail-bearers had been fixed upon the main girders, the side-platforms of the travelling stage were removed and stacked upon the cross-girders, and preparations were then made for moving the stage to the next span. This operation required much care, on account of the great length and weight of the stage and the slenderness of the tall piers over which it had to travel. Before the commencement of the movement the stage was between the girders of the bridge, and was resting on rollers on the two piers, 130 feet apart, while the remaining length of 63 feet overhung into the next span forwards. At the back end of the stage, which was specially stiffened, a wheel and axle were now fixed in bearings upon each side, at such a height as to run upon the inside flanges of the bottom booms of the girders. As there were rivet-heads along these flanges, steel strips, of the thickness of the heads and perforated to receive them, were fixed upon them, and thus a smooth path was provided for the wheels to run upon. At the beginning of the movement the weight upon these two wheels was approximately 30 tons, but it is obvious that the load on the trailing wheels was gradually

reduced by the forward motion of the stage; and, when the centre of gravity arrived at the roller frame upon the pier, no further support was needed at the rear end. To allow of the further movement of the stage without tipping, a pair of flanged guide-wheels was mounted over each truss of the stage, running in bearings which were attached to timber framing on each side of the central cross-girder, so that the whole weight of the span last erected was called into play as a counterbalance. The guide-wheels were mounted immediately over the rails, which have before been mentioned as forming a road for the travelling hand-crane, and which bore against the guide-wheels, as the stage travelled forwards. The motive power for moving the stage was obtained by block-tackle worked by hand-winches; a set of blocks was fixed on each side, one block being fixed to the bottom boom of the girder at its forward end, and the other block being made fast to the bottom boom of the stage; the leading parts of the falls being taken directly, or, when necessary, through snatch-blocks, to the winches, which stood on the cross-girders on the top of the bridge. It has been roughly calculated that the tractive force necessary to move the stage forward was about 13 tons.

As soon as the point of the stage reached the next pier, men were sent across and the point was temporarily packed up, and then the rollers which had been left behind on the backward pier were taken across and were fixed under the point. The point was now eased up with jacks and the wheels were removed from between the cross-girders at the back end of the stage, and then the point was lowered on to the rollers just fixed. The stage was now again resting upon rollers upon two piers, and the movement was continued forwards for the remaining 60 feet, until the stage occupied the right position (in point of distance) for building the girders of the next span upon it. Owing, however, to the viaduct being built upon a curve, the stage had now to be moved sideways upon the forward pier. For this purpose the stage was lifted again by four hydraulic jacks, the rollers were removed and were replaced by a planed bridge-rail bolted to a timber which was laid upon the pier transversely under the stage. When resting on this rail, which was well greased, it was comparatively easy to move the stage sideways by means of jacks, aided by union-screws attached to the holding-down bolts which were built into the pier. As soon as the forward end had been moved to the centre of the pier it was again lifted, the rail was removed, and the rollers replaced ready for the next move forwards.

The side platforms were then fixed and the stage was ready to receive the girders of another span.

When the stage was moved forward in fairly calm weather, it was not difficult to keep it travelling in a straight line upon its rollers. On the other hand, it was impossible to move it during a strong side wind, owing to the large surface offered by the stage, and the leverage at which the wind-pressure acted when a large length of the stage was overhanging without support. A distinct vibration was felt in the piers during the moving of the stage.

In conclusion, it may be remarked that the appliances which have here been described were perfectly successful in the accomplishment of the work for which they were designed; and the method of erection was found to be convenient, expeditious and well adapted to the situation.

The Paper was accompanied by two tracings from which the Figures in the text have been prepared.

(*Paper No. 3126.*)

"The Failure of the Embabeh Bridge, Cairo."

By Frederick Ewart Robertson, C.I.E., M. Inst. C.E.

The Embabeh bridge over the Nile connects the railway system which centres in Cairo with that of Upper Egypt. It is a single-line through bridge of eight continuous spans and a swing-span; the ordinary spans are 243 feet, the end spans 203 feet 4 inches long, and each arm of the swing-span is 94 feet 3 inches long between centres. There is a corbelled-out passage 14 feet wide for cart traffic on each side. The bridge was built by contract under open competition, the general conditions only being specified; the designs and the tenders were examined by a committee of engineers in the service of the Egyptian Government, on which the railway was represented, and the work was allotted to a well-known French firm. An ordinary span and the swing-span are illustrated in Figs. 1 and 2, Plate 3, respectively. The lateral bracing at the top and bottom was of adequate design.

The unit stresses in all members required by the specification were:—

	Tons per Square Inch.
Wrought iron in compression	3·82
" " " tension	4·45
Steel in compression	5·1
" " tension	7·0

The process by which the steel was to be made was not mentioned, nor were chemical restrictions imposed in regard to its composition. Hot punching and bending tests were specified, and the minimum tensile strength prescribed was 28·6 tons, with an elongation of 20 per cent. in 200 millimetres, subsequently revised to 26–29 tons, and an extension 26 per cent. to 22 per cent. It was prescribed that for pieces less than 10 millimetres thick the punched hole must be 3 millimetres less than the finished hole, the rest being drilled out, and for pieces thicker then 10 millimetres, 4 millimetres less; and that in the case of the metal not behaving well under the punch the contractor might be required to drill the holes entirely.

The contractors were afterwards permitted to punch the holes of the full size. The bridge was to be tested by a full train of the heaviest locomotives, with carts on the roadways, and it was further provided that the contractor was to be liable for a year after the bridge had been put into service to make good any defects that might be discovered. The girders were erected by launching over rollers on a rigid bed, and the bridge was opened in May, 1892. It may be noted that after the designs were accepted by the committee, the detailed calculations were checked by a French engineer.

The bridge worked satisfactorily until the morning of the 4th December, 1896, when the west downstream arm of the swing-span was found torn in two, as shown in Figs. 3, 4 and 5. Traffic was suspended, and the pieces that had failed were cut out and were replaced by stronger sections, and before being put into service the bridge was again tested by a full train of locomotives. An examination of the member revealed an old crack which reduced the effective section of the chord by one-third, and from the circumstances that paint was found in the crack it was known to be at least 2 years old, but probably it had opened wider at the time of the failure. A committee was appointed to study the bridge, but before any conclusion was arrived at, the upstream west arm split across on the morning of 26th January, 1897, similarly to the other arm, as shown in Fig. 5. The split pieces were again replaced by stronger sections, but the bridge was not tested by a string of locomotives before being put again into use.

The committee reported that they found a considerable number of cracks in the edges of the chord plates, especially of the spans that had passed over most rollers in the process of launching, and that as the tests of the metal made at the time of building the bridge showed it to be soft steel, while the broken pieces appeared to be hard, it was probable that vibration had caused a molecular change. The committee also drew attention to the fact that the passage of a single donkey on the roadway produced more vibration than the passage of a train, and recommended that the width of the roadways should be reduced. They further recommended that measures should be taken to strengthen the bridge up to the limiting stresses now in use, that until the work was completed only the lightest type of engines should be allowed to cross the bridge, and that when the work was finished the bridge should again be "tested" with live and dead loads as if it were a new bridge.

No action had been taken on this report when the Author joined

the Egyptian railways as President of the Board at the end of March, 1897. He considered the continuous spans, to which no attention had hitherto been given, more dangerous than the swing-span, on account of their want of lateral stability. He therefore stopped the road traffic entirely, and confined the rail traffic to that taken by a small engine weighing 18 tons. The employment of basic Bessemer steel and punched holes appeared sufficient to account for the fractures. It was observed that in places where the cracks crossed a rivet-hole they ran out of their course on meeting the ring of metal hardened by punching; a crack could thus have been traced to its point of origin.

Tests of the metal during the construction of the bridge are given in Appendix I, and the results of chemical and mechanical tests of pieces cut from the split plates are given in Tables I–III. Pieces bearing the same numbers are either identical, as in the case of analysis of a piece after pulling it, or adjacent, as where one strip is pulled and the other is bent.

TABLE I.—CHEMICAL TESTS.

—	No. 1 Up-stream.	No. 5 Up-stream.	Angle No. 6 Up-stream.	Angle No. 9 Down-stream.	No. 13 Down-stream.	No. 16 Down-stream.
Carbon	0·063	0·057	0·105	0·068	0·057	0·064
Silicon	0·006	0·007	0·006	0·006	0·004	0·007
Sulphur	0·034	0·039	0·030	0·037	0·034	0·023
Phosphorus	0·070	0·092	0·094	0·094	0·097	0·074
Manganese	0·396	0·353	0·626	0·634	0·500	0·522

The general length of the tensile test-pieces was 1·18 inch, and width of the strips for bending 1 inch to 1½ inch.

Some of the plates were also examined microscopically both parallel and perpendicular to the surface of the plate, with the result that nothing abnormal was discovered. The effect of rolling appeared evident in the structure of those samples which had a higher tensile strength than would be inferred from their composition.

It was finally decided to replace the swing-span by another of adequate design and more trustworthy metal. As for the continuous spans, seeing that the span was much greater than the economical limit, on account of the impossibly light girders assumed, and greater than the regimen of the river required, the obvious course was to erect additional piers and to strengthen the

TABLE II.—TENSILE TESTS.

Plates.	Direction of Cut.	Elastic Limit.	Maximum Stress.	Elongation.	Contraction of Area.
		Tons per Sq. Inch.	Tons per Sq. Inch.	Per cent.	Per cent.
No. 1 upstream . .	Transverse .	13·81	27·28	23·5	48·3
„ 2 „ . .	Longitudinal	21·10	27·80	26·0	53·2
„ 3 „ . .	„	21·65	27·32	26·5	52·5
„ 4 „ . .	Transverse .	23·86	29·45	24·0	46·5
„ 5 „ . .	Longitudinal	21·53	28·23	28·5	51·9
„ 6 „ . .	„	20·57	29·23	31·0	55·3
„ 7 „ . .	„	17·66	26·10	31·8	59·1
„ 8 „ . .	„	18·30	26·86	33·2	60·8
„ 9 „ . .	„	20·55	29·19	30·0	58·2
„ 10 downstream .	Transverse .	19·77	23·17	4·5	7·3
„ 11 „ .	Longitudinal	17·15	18·40	4·0	24·5
„ 12 „ .	„	20·81	27·23	20·5	57·7
„ 13 „ .	Transverse .	23·18	29·87	21·0	41·4
„ 14 „ .	Longitudinal	19·52	32·00	27·67	61·1
„ 15 „ .	Transverse .	18·86	20·00	5·5	29·5
„ 16[1] „ .	Longitudinal	22·81	28·59	26·8	57·9
„ 17[1] „ .	Transverse .	23·31	29·94	22·5	43·4

TABLE III.—BENDING TESTS.

The test pieces were bent round a 1-inch rod till the ends met.

Plates.	——	Direction of Cut.	Remarks.
No. 1 upstream .	Untempered	Transverse .	No cracks.
„ 3 „ .	Tempered .	„	Skin cracks.
„ 3 „ .	Untempered	„	„ „
„ 6 „ .	„	Longitudinal	No cracks.
„ 7 „ .	„	„	Cracked through opposite rivet-hole; ends bent within 1 inch.
„ 8 downstream	„	„	No cracks.
„ 9 „	„	„	„ „
„ 10 „	„	Transverse .	Skin cracks.
„ 10 „	Tempered .	„	Cracked at flaw in plate.
„ 11 „	Untempered	Longitudinal	No cracks.
„ 11 „	Tempered .	„	Cracked at flaw.
„ 12 „	Untempered	„	No cracks.
„ 13 „	„	Transverse .	„ „
„ 14 „	„	Longitudinal	Skin cracks.
„ 15 „	„	Transverse .	No cracks.

[1] Test-pieces cut as far from the flaw as possible. The remainder of the pieces were cut as near the crack as possible.

braces by riveting deep angle-bars to their backs, adding also a stiff girder to carry the outer ends of the footway brackets. This will reduce the stresses to about a quarter of those originally contemplated and will vastly increase the stiffness of the bridge. The repairs will probably enable it to last a good many years, and, even should the girders eventually fail, the new piers will serve.

The use of basic Bessemer steel and punched holes, aggravated by ill-treatment in rolling out over rigid rollers, are enough to account for cracks; but why the first failure did not take place through the old crack, which was the weakest place in the member, or why a month afterwards the symmetrically opposite member should have failed in a similar way, has not been explained. The stresses at that place do not account for it, and the only plausible theory is that that arm of the swing-span must have sustained some injury during erection.

It seems almost incredible that two angle-bars 3·1 inches by 0·3 inch, and 34 feet long, should be considered to form an adequate strut, even though crossed by three similar pieces. The error was obvious; the braces were calculated as columns fixed at their intersections. Not only are they no more fixed in a mechanical sense by the other flimsy members that cross them than are the threads of a net, but they are not even fixed at the ends, being attached to a single plate 18 inches wide and 0·3 inch thick, which, in every bridge of this type within the Author's experience, has become or has always been buckled.

A word of protest must be added against the idea of "testing" a bridge, which still survives. In the present case the bridge failed twice in spite of—and in one case immediately after—the "tests," on the strength of which it was pronounced satisfactory They in reality hastened the catastrophe, yet a committee of engineers recommend that when the bridge has been strengthened the "tests" should be repeated.

The Paper is accompanied by six drawings and a photograph, from which Plate 3 has been prepared.

APPENDIX.

Tests of Metal for Embabeh Bridge.

	No. of Tests made.	Elastic Limit, Tons per Square Inch.			Tensile Strength, Tons per Sq. Inch.			Elongation per cent. on 8 inches.			Contraction of Area, per cent.		
		Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.
Plates lengthways.	2	17·2	17·5	17·8	26·6	26·6	26·6	25·0	26·5	28·0	47·0	54·0	60·9
	10	14·6	17·4	19·1	24·9	26·8	28·6	27·0	29·7	32·0	54·1	60·0	63·0
	10	16·5	17·1	18·4	26·0	26·5	28·0	23·0	27·3	32·0	50·0	55·4	64·7
	3	17·0	17·8	18·3	26·2	26·7	27·5	26·0	26·8	28·0	52·6	54·5	56·0
	9	17·3	18·0	19·1	26·7	27·7	29·0	24·5	27·5	30·0	50·0	58·2	67·5
	5	17·8	18·2	19·1	26·7	27·0	28·2	26·0	26·7	27·5	54·8	60·6	68·0
Plates crossways.	2	17·2	17·2	17·2	26·2	26·3	26·4	26·0	28·0	30·0	57·3	61·2	65·1
	10	16·5	19·5	22·2	27·0	28·0	29·9	20·0	23·4	30·0	44·3	50·4	56·8
	10	16·5	17·4	18·4	26·0	27·7	28·5	22·0	26·4	32·0	39·3	48·2	55·1
	3	17·8	18·0	18·2	26·4	26·6	26·7	26·0	27·0	28·0	55·2	57·7	60·6
	9	16·8	17·5	18·5	26·3	27·5	28·8	24·5	25·6	28·0	46·0	56·3	60·8
	5	16·5	17·3	18·4	26·8	27·5	28·5	26·0	26·5	27·0	57·6	59·2	61·9
Angles.	16	15·2	17·5	17·8	26·4	27·4	28·5	25·0	30·4	35·0	56·3	60·8	66·2
	4	16·5	17·8	18·7	26·9	27·6	28·4	32·0	33·0	35·0	61·2	61·8	62·7
	16	16·5	17·4	17·8	26·0	27·3	28·1	24·0	35·1	34·0	52·0	60·0	67·2
	12	16·8	17·7	18·7	26·4	27·3	28·0	26·0	28·3	31·0	58·0	62·3	66·2
	9	16·5	17·0	17·8	26·6	27·5	28·4	25·0	27·8	29·0	51·0	62·1	69·3
	8	16·7	17·5	18·1	26·0	27·1	28·3	26·0	30·0	32·0	50·0	57·8	70·0
Flats.	7	14·6	15·6	17·1	26·1	27·6	29·0	25·0	29·3	33·0	58·3	62·1	68·3
	2	16·5	17·1	17·7	26·0	26·4	26·6	28·0	29·0	30·0	62·2	62·6	63·1
	2	16·5	16·8	17·1	26·3	27·0	27·7	24·0	26·0	28·0	53·7	56·5	59·4
	10	16·7	17·4	18·0	26·0	27·1	28·0	23·5	27·5	32·0	49·2	60·8	70·0

Many shop tests for splitting, bending, &c., were also satisfactorily performed.

(*Paper No. 3118.*)

"The Pahartali Locomotive and Carriage Works, Assam-Bengal Railway."

By Charles Frederick Bamford, Assoc. M. Inst. C.E.

The site of the Locomotive and Carriage Works of the Assam-Bengal Railway was chosen at a sufficiently high level to avoid damage from tidal waves, and in close proximity to the main line and to the terminal station at Chittagong. The surrounding land is capable of being well drained and is free from jungle; it is, as far as possible, healthy, and suitable for the erection of quarters for labourers and mechanics. The shops are lighted from the north to minimise the heat from the midday and afternoon sun, and the roofs of the buildings are arranged with their slopes of least resistance in line with the direction of the prevailing winds, which come from the south and south-west, and were designed to resist cyclones. The shops were also laid out so that the proper sequence of operations could be followed, to minimise labour and thus lessen the cost of construction and repair of the rolling stock.

The general arrangement of the workshops and lines of rails connected to the north side of the main line is shown in Fig. 1, Plate 4. They are situated $2\frac{3}{4}$ miles distant from Chittagong terminal station of the Assam-Bengal Railway, and 1·87 mile from Chittagong Port, to which a branch runs from the main line at Pahartali. The three buildings, viz., foundry and smith shops, the machinery and erecting shops, and the carriage upholstering, painting and wagon shops, are placed side by side 80 feet apart; each is capable of future extension southwards. The centre line of the 40-foot steam-carriage traverser extends 800 feet east and west, and is 90 feet from the north frontage-line of the three main buildings. Twelve lines are laid at right angles from the traverser-line into the carriage upholstering, painting, and wagon shops, and three lines from the traverser through the erecting shop are connected with the workshop siding on the south side of the shops. The 40-foot steam traverser is also connected up

from the south to the workshop siding by four lines running between and on each side of the three buildings.

The Saw-Mill and Carriage-Building Shop is placed on the north-side of traverser, opposite the carriage and wagon shop, 180 feet distant. Three lines are laid at right angles from the traverser line into the saw-mill and carriage-building shop, and at the north-east end of the traverser line are ten lines, for building and repairing iron wagons, and a line is laid completely round the shop to terminate at a turntable placed inside of the north-east corner of the boundary.

The Time-Keeper's Office and tank-house has been placed at the north-west side of the workshop yard, and water is pumped to it from a well 650 feet distant. From this tank-house water is supplied to the shops and to engine shed. The site is also suitable for the time-keeper's office, as it is in close proximity to the station.

The Engine Shed, which will be capable of holding sixteen engines and tenders when the extensions have been completed, has been placed opposite to Pahartali station and outside the north end of boundary wall; four lines pass through the shed and along each side of the building. Outside both ends of the engine-shed inspection pits are placed under each line, each 53 feet 6 inches in length.

The General Store Building is situated opposite the foundry and smith shop, with store-yard at back covering an area of 61,193 square yards, and railed off from the locomotive yard by a wooden paling. A line is led from the workshop siding, through a gate into the store-yard at the south end, and out again at the north-east corner, terminating at the turntable placed at the north-east corner of locomotive-yard.

The General Locomotive Superintendent's Office is a building of one storey, having a verandah on each side of the different offices so that a circulation of air can pass through each room from the doors and windows that look out on to the verandahs for coolness.

Outside the west boundary-wall and parallel to the main line are three lines for carriage sidings, covering a length of 4,500 feet. In close proximity to the engine-shed has been placed a locomotive and carriage weigh-bridge and turntable, and between the machine and carriage and wagon-shops has been placed a carriage-examining pit 150 feet in length.

The Erecting and Machine-Fitting Shops, Fig. 2, Plate 4, are contained in one building, measuring 200 feet by 164 feet 7 inches, which is separately divided by brick walls with arched openings into three divisions, each measuring 40 feet clear. The outside

walls are 18 inches thick and have projecting pilasters, base cornice, and parapet wall. The walls are carried down 5 feet $7\frac{1}{2}$ inches below the floor-level, and rest on 1 foot 6 inches of concrete. The openings with semi-circular tops measure 12 feet 6 inches by 13 feet to crown. The division-walls, between the erecting shop and the machine and fitting shops are 2 feet 6 inches thick from the ground-level up to a height of 2 feet, and 2 feet 1 inch thick to the roof. The buttresses that carry the longitudinal traverser-girders are 1 foot 3 inches thick, by 2 feet 6 inches in width, also those that carry the cross-girders are 1 foot 3 inches thick, by 2 feet 6 inches. The arched openings with semi-circular tops between the buttresses measure 14 feet 2 inches by 15 feet 6 inches to crown. The centre division comprises the erecting shop; the east and west division, the machinery and fitting shop. These divisions are spanned by N girders, 20 feet apart, carried on bed-stones let into the buttress-walls.

The girders in the erecting shop measure 43 feet 4 inches over all, and are divided into six bays 7 feet $3\frac{1}{8}$ inch centres; those in the machinery and fitting shops are 41 feet 10 inches over all by 3 feet deep, and are divided into six bays, 6 feet $8\frac{1}{8}$ inches centres carrying at each apex a light roof truss. The upper boom consists of one plate 41 feet 10 inches by 1 foot 6 inches by $\frac{3}{8}$ inch, two L's 4 inches by 3 inches by $\frac{7}{16}$ inch, and the bottom boom of one plate extending over two centre bays, 16 feet by 1 foot 6 inches by $\frac{3}{8}$ inch. The vertical struts are each made up of four L's 3 inches by 2 inches by $\frac{5}{16}$ inch, which are riveted on to the angle-irons of the upper and lower booms. The diagonal tension members are made up as follows: end bays, two bars $3\frac{1}{2}$ inches by $\frac{13}{16}$ inch, second bays, two bars 3 inches by $\frac{5}{8}$ inch, centre bays each two bars $3\frac{1}{2}$ inches by $\frac{7}{16}$ inch, and two bars 3 inches by $\frac{3}{8}$ inch. The trusses that are carried on these girders are saw-shaped and carry the corrugated-iron roofing. These measure 19 feet $3\frac{1}{2}$ inches from centre to centre of intersections. The rise to the apex of pitch-line measures 6 feet $3\frac{7}{8}$ inches, which is set back 2 feet $4\frac{3}{8}$ inches horizontally from centre of intersection. The rafters are built up of T's 4 inches by $3\frac{1}{2}$ inches, by $\frac{9}{16}$ inch, and main tension members of 1 inch diameter rods; the short compression members are placed at right angles and are bolted to the main rafters set at a distance of 9 feet $\frac{7}{16}$ inch from end; they are also bolted at the lower end to the centre of the main tension members, which are two flat bars $2\frac{1}{2}$ inches by $\frac{5}{16}$ inch, bolted at ends to the T I rafter and rod tension member; these bars are kept at a distance of

3 inches apart at the centre by cast-iron ferrules. The diagonal-tension tie-rod is 1 inch in diameter with forged eye, bolted to gusset-plate, connecting the T rafters at their apexes, and also connected at the lower end, which is forked with forged eye, and pinned to the centre of the main tie-bar. The acute pitched rafter T iron carries the four L I purlins, which carry the corrugated-iron 18 B. W. G. flute, 3 inches by $\frac{3}{4}$ inch sheet roofing; these purlins are connected to the rafter by means of L I cleats. The obtuse pitched T-bar rafters carry the teakwood window-frames and windows that face the north. The gutters are of a large section, so as to carry away the heavy monsoon rainfall, and are made of thin sheet steel $\frac{1}{8}$ inch thick and bolted to the L I purlins at the ends of the trusses.

In the erecting shop the height from floor-level to the bottom boom of the cross-girders is 28 feet; this height has been given so as to allow sufficient headway for a 30-ton traverser, which is carried on longitudinal rails and girders resting on the side-wall buttresses. This traverser is driven from the main shafting by rope gearing attached to the side walls. Between the two lines of rails that pass through the erecting shop are brick engine-pits 2 feet 9 inches wide by 3 feet $7\frac{1}{2}$ inches deep. A third pair of rails passes down the centre.

The Erecting Shop has accommodation for sixteen locomotives. The frame plates are taken to a vacant berth on the side road of the erecting shop, and are there fixed in position over the engine pit. The cylinders are then fixed, and the boiler, by the aid of the travelling crane, is lifted into its place on the frame from the centre road, and the wheels with axles and axle-boxes placed under. The eccentric and connecting-rods having been fixed, and the valves set, the locomotive is lifted upon the running road that passes down the centre of the shop, and drawn to the weigh-bridge where the weight on each wheel is adjusted. It is then tested by water- and steam-pressure, and, with its tender, which is constructed in another part of the erecting shop, it is taken by the carrying traverser to the paint shop.

The Machine and Fitting Shops are arranged in two bays, each measuring 200 feet long by 40 feet wide; they extend along and are placed on the east and west side of the erecting shop, and are divided off by brick walls with arched openings and semi-circular tops, measuring 14 feet wide by 15 feet 9 inches to crown of arch; these openings are 20 feet apart from centre to centre and are spaced between the buttresses carrying the cross girders. The outside, east and west walls have openings with semi-circular

tops measuring 12 feet wide by 13 feet to crown; these openings are filled in with honeycomb 15-inch brickwork, or doors and windows as desired. The height from floor-level to bottom boom of cross girders is 18 feet. In both divisions two main shafts are carried along each of the side walls, and pass between the end bays of the cross girders; these shafts are supported by cast-iron brackets attached to the side walls and connected by belting. From the four main shafts are driven counter shafts, supported at a lower level in bearings with brackets bolted to the side walls, from which are driven the light and heavy machines; arrangement is also made for four other counter shafts being carried in bearings supported on the bottom boom between the second bays of the cross girders. The machine and fitting shop is provided with a large number of turning lathes, planing, shaping, milling, slotting, drilling, screwing and tapping machines. These tools are arranged in rows along the shop and driven from the overhead counter shafts. The machines stand upon solid brick and concrete beds. Also a number of benches is supplied for fitting work and setting out purposes. Running along the centre of the bay in each division is a single rail along which runs a walking jib crane, supported at the top in box girders attached to the centre of the cross girders and driven by overhead rope gearing. These cranes are used for lifting heavy pieces of machines and castings on and off the heavy lathes and machines placed on each side near the centre of the building. On the floor between the two rows of light and heavy machinery runs a light narrow-gauge line for use in transporting the materials required to be moved between the various shops. The engine-house measures 20 feet by 20 feet, and is joined on to the east side of the machine shop. The engine is of the compound horizontal type. The main shaft in the machine shop is driven directly off the main driving fly-wheel pulley by manilla rope belting. The steam-pipe from the Galloway boilers placed beside the foundry is carried across on columns.

The Carriage Upholstering, Painting and Wagon Shops, Figs. 3, Plate 4, are contained in a building measuring 200 feet long by 212 feet 1 inch in width. This department is bounded on the east by the machine and erecting shop and on the north by the saw-mill. The outside walls are 18 inches thick and have projecting pilasters, base cornice, and parapet wall; the walls are carried down 5 feet 7½ inches below floor-level and rest on concrete foundations. The door openings measure 12 feet 6 inches by 13 feet to semi-circular tops. The bays five in number, each 42 feet, are placed transversely to the line of rails. Three lines of rails

extend down the whole length of the shop between each of the four bays, making a total of twelve tracks; the fifth bay is utilized for fitting benches and machinery, also for upholstering and painting materials. The wrought-iron roof trusses are each 20 feet span, and similar to those adopted for the machine shop; they are carried on lattice girders supported by cast-iron H columns. The latter, 18 feet 1½ inch in length, are bolted on to concrete foundations; they are placed 20 feet apart, and between spans 42 feet apart. The top of each cast-iron column is in the form of a square, to which the girders are bolted. The girders measure 41 feet 11¾ inches over all, which allows ¼ inch for expansion at one end. They are similar to those used in the machine shop.

The Smith Shop and Foundry, Figs. 4, Plate 4, are placed together in one building, which measures 202 feet 6 inches long by 128 feet 11 inches wide. It is divided into three bays, which are spanned by N girders similar to those in the carriage shop; these girders are spaced 20 feet apart and are carried on cast-iron H columns. The ends of the outside girders are carried on bed-stones fixed in the two side walls. On these girders are fixed the trusses, similar to those adopted in the machine and carriage shops, and so placed that the windows face north. The cross girders are braced together by light longitudinal lattice N girders, 1 foot deep at centre, with ends arched down to 3 feet deep; these are bolted to the cross girders, and at the ends of the building to the end walls. The walls on which the cross girders rest are 18 inches thick with arched openings measuring 12 feet 6 inches by 13 feet; those that are not required for doors or windows are filled with honeycomb brickwork to allow air to pass through for coolness.

Extending along the west side of the building is a 20-foot covered verandah, under which is placed the Galloway boiler for supplying steam to the machine shop; also the faggoting, tire and spring furnaces. The smoke, etc. from these furnaces is carried away by flues to the main chimney, measuring from ground-level 90 feet high, having a 3-foot 6-inch diameter opening at top. The grate area required for the furnaces is as follows:—

	Square Feet.
Two Galloway boilers	48·00
Faggoting furnace	11·00
Tire furnace	11·00
Spring furnace	5·75
Total grate area	75·75

In calculating the required area of chimney, the mean outside temperature was taken at 100° F., which is higher than the usual practice in England. The temperature of the furnace gas was taken at 600° F. absolute, which gave an available head of 98·5 feet. The velocity of air amounted to 9·93 feet per second, not including friction. After taking into account the resistance in flues at 0·012, and that of the grate at 12, the velocity of air was reduced to 4·83 feet per second. The flues and the chimney are built of brick, the latter having an outside batter of 1 in 45, to a height of 90 feet above ground-level. The cap is provided with square wind ports. The brickwork is carried down 9 feet below ground-level, and rests on a concrete base foundation. The flues are completely lined with fire-brick; also a fire-brick lining is carried up the chimney to a height of 38 feet 6 inches. It was considered that this design was the best to resist cyclones. On the 24th October, 1897, a velocity of over 100 miles per hour was recorded, and a large amount of property was destroyed, and caused a loss of several thousand lives. The lower portion of the chimney is, to a great extent, sheltered from the wind by the surrounding shops. Under the north end of the verandah are placed the punching, shearing, plate-bending and spring-testing machines; also a vertical double cylinder wall engine, which supplies power to these machines, and driving two rotary blowers which are placed on the inside of the north wall of the building. These blowers supply forced draught to a series of open hearths and one annular hearth; also to the Fletcher furnace for heating the core-oven. The brass-foundry, with core-oven and foreman's office, is placed by the centre at the east side of the building. The brass-foundry measures 20 feet by 20 feet, the core-oven 20 feet by 10 feet, and foreman's office 20 feet by 10 feet; this section is enclosed by a brick wall. The heat for the core-oven is supplied by a Fletcher furnace placed outside, the products of combustion being carried round the oven by a 10-inch by 10-inch flue, and afterwards up the chimney placed at one corner of the oven. This flue is built of fire-brick, and rises 1 in 60 from Fletcher furnace to foot of chimney. The iron-foundry covers an area of 4,100 square feet, and is placed at the north-east end of the building. The cupola is placed outside the east wall, air being supplied to it through a 5-inch pipe from one of the rotary blowers.

The Saw-Mill and Carriage-Building Shop is placed on the north side of the carriage and wagon shop, and measures 198 feet 4 inches by 124 feet 9 inches inside. It is divided into three

bays, spanned by 42 feet N girders, on which rest the 20-foot trusses; the girders rest on cast-iron columns, and the outside ends of the girders on to the east and west walls. The girders, trusses, and columns, are similar to those adopted in the carriage and wagon shop, with window lights facing north. Between the east bay are run three pairs of lines, which are connected up on the south side to the main carriage traverser. Between the centre and west bays are placed the different saw machinery, including saws, breakdown, mortising machines, etc. The machinery is driven from a double fly-wheel, compound, horizontal engine, placed in an engine-house measuring 60 feet by 14 feet 6 inches; this house is joined on to the centre of the west outside wall of the building. From each fly-wheel is driven a separate shaft, running below ground-level in 6-foot shafting pits, placed 50 feet apart and extending 43 feet from the west to east of the building.

The Tank-House, with Time-keeper's Office on the ground and first floor, is placed at the north-west corner of the yard, and is in close proximity to Pahartali station. The fifteen wrought-iron tanks, measuring 8 feet by 8 feet by 6 feet inside, and weighing about 35 cwt., each with pipes, are arranged in five rows of three tanks; between each tank is a space of 1 foot 2 inches. The tanks are connected to each other by 6-inch pipes. The total tank-area is 4,760 cubic feet, with a capacity of 29,750 gallons of water. The height from the ground-level to the bottom of the tank is 35 feet 1½ inch, giving mean average head of 37 feet. Water to the locomotive shed and to the workshops is supplied through a 6-inch diameter pipe. The tank-house is designed so that if increased water-capacity is ever required a second tier of 6-foot tanks may be mounted on the top of the lower tanks. On the ground floor, in the centre of the building, is the main entrance hall, and on each side is a time clerk's office. Entrance for workmen to the workshop yard is made from the north, through double folding wrought-iron gates, and out into the yard from the south side through Norton registering workmen turnstiles. On the first floor is the time office, measuring 36 feet 6 inches by 15 feet clear. At the east end of the building is an outside covered stair-way leading from the ground to the first floor.

The Paint and Varnish Shop measures 56 feet by 40 feet, and is spanned by two 40-foot N girders, on which rest the 20-foot saw-shaped trusses that are similar to those adopted in the machine and other shops having their lights facing north. The walls are 1 foot 6 inches thick, with a 3-foot base of concrete. The height

from floor-level to the bottom boom of the N girders measures 18 feet clear. The walls are intersected by arched openings, in which are placed the necessary doors or windows. The arched openings that are not required for doors or windows are filled in with honeycomb brickwork to allow for ventilation.

The General Stores measure internally 178 feet 6 inches by 82 feet 9 inches, and are spanned by two 42-foot N girders, on which rest the 20-foot saw-shaped trusses, similar to those adopted in the paint and varnish shop with their lights facing north; on the east side is a covered verandah running the length of the building, besides which a rail track is laid. This building is provided with shelves, racks, and lock-up cupboards for carrying and holding the different stores.

The Engine Shed at present measures 179 feet by 35 feet inside, and is capable of extension of another bay 179 feet by 35 feet on the west side; ashpits are placed under each track, and stand-pipes, with hoses for washing-out purpose, are placed down the centre of the building, water being supplied from the tank-house. The corrugated-iron roofing is carried by 37-foot trusses placed 10 feet apart. The smoke uptakes are taken through the roof, from which they are suspended over the centre of each ashpit.

The total cost of the buildings, engine-pits, steam-traverser, turntables, etc., was £69,273; the following Table shows that of the principal portions of the work:—

	Rs.	£	s.	d.
Machine and erecting shops, including erecting machinery, two ashpits and engine-house	1,90,365	12,691	0	0
Smith-shops and foundry, including office and core-oven	1,61,603	10,773	10	8
Carriage upholstering, painting and wagon shed	1,56,972	10,464	16	0
Carriage-shop and saw-mill	1,40,415	9,361	0	0
Tank-house and time-office	27,518	1,834	10	8
Locomotive Superintendent's office	35,797	2,386	9	4
General-store shed	94,980	6,332	0	0
Paint and oil shed	24,449	1,629	18	8
Steam-traverser	34,775	2,318	6	8
Engine shed	58,655	3,910	6	8

With the exception of the ironwork, which was contracted for and obtained from England, the whole of this work was constructed and erected departmentally.

All the labour employed in the various shops was imported. The mechanics, fitters, and smiths, are men from Bengal and the Central Provinces of India. The carpenters employed on pattern-

making, carriage-building, and other works are Chinamen. Each department is under skilled European supervision.

Most of the iron- and machine-work for the various portions of the rolling stock is obtained from England, and built up and erected in these shops; the majority of timber used is of teak, which is obtained from Burma and India.

The Paper is accompanied by 7 drawings, from which Plate 4 has been prepared.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

The locomotive engines and tenders used on the Assam-Bengal Railway are built for the metre gauge, and are specially designed for running over heavy gradients of 1 in 35 and round sharp curves of 10°, which occur over a distance of 120 miles through the hill section of this railway, the total length of the line being 733 miles; the total weight of engine and tender, in working order, being 38 tons 3 cwt. 1 qr. 0 lb. The general dimensions and capacity of the engines and tenders are as follows:—

For engine—

Diameter of cylinder	14 inches.
Length of stroke	20 inches.
Diameter of coupled wheels	3 feet 6½ inches.
Wheel base	11 feet.
Working steam pressure per square inch . . .	140 lbs.
Heating surface (external tubes)	590 square feet.
„ „ (fire-box)	60·6 „ „
Grate area	12 „ „

For six-wheeled tenders—

Wheel base	7 feet 10½ inches.
Diameter of wheels	2 feet 1⅝ inch.
Capacity of tank	1,000 gallons.
Fuel space	230 cubic feet.

APPENDIX II.

The South Indian Railway workshops at Nagapatam were originally designed to serve about 200 miles of the 5-feet 6-inch gauge railway, but since 1875 the railway has been converted into metre gauge, and at present the total length is over 1,049 miles. The workshops have, therefore, been considerably enlarged.

The following Table shows the cost of machinery, including its erection for each shop, up to the end of 1894:—

Item No.	Names of Shops.	Cost of				
		Machinery.	Shafting and Pulleys.	Erection.	Miscellaneous Tools.	Total.
		Rs.	Rs.	Rs.	Rs.	Rs.
1	Carriage-shop .	51,621	2,752	5,437	29,500	89,310
2	Tool-shop . .	1,77,372	11,865	18,923	16,000	2,24,160
3	Boiler-shop . .	26,088	2,860	2,894	12,000	43,842
4	Smith-shop . .	26,952	..	2,695	18,000	47,647
5	Foundry . . .	6,007	..	600	19,000	25,607
6	Erecting shop .	20,730	..	2,073	17,000	39,803
7	New tank-house .	4,260	..	426	50	4,736
	Grand total .	3,13,030	17,477	33,048	1,11,550	4,75,105

APPENDIX III.

The construction of the Southern Maharatta metre-gauge railway workshop at Hubli was completed in 1888, and, as originally designed, was intended to serve 800 miles of railway, but with the increase of extensions, the total mileage at present amounts to over 1,556 miles.

The expenditure incurred on buildings, etc., amounted to Rs.15,12,000, and Rs.3,30,456 on machinery and tools. Each large engine-changing station has been supplied with one lathe, one shaping machine and one drilling machine, in addition to the usual equipment of tools, in order to facilitate light repairs. The following is an abstract of the cost of machinery and tools, including the erection of same for each workshop originally designed to serve 800 miles, and also a further estimated amount for complete equipment to serve 1,556 miles. These totals are summed together, amounting to Rs.10,00,000, expended on machinery and tools up to the end of 1894:—

No.	Names of Shops.	Machinery.	Shafting, Pulleys, Girders, etc.	Erection.	Miscellaneous Tools.	Total.
		Rs.	Rs.	Rs.	Rs.	Rs.
1	Machine- and fitting-shops	3,20,476	21,222	41,990	18,809	4,02,497
2	Grinding-shop . . .	8,068	960	1,109	707	10,844
3	Erecting-shop	45,591	..	3,558	16,764	65,913
4	Boiler-shop	64,298	6,382	7,933	15,283	93,896
5	Smithy	85,528	5,214	10,023	17,529	1,18,294
6	Foundry and pattern-shop	33,549	485	3,727	6,407	44,168
7	Coppersmithy and tin-smithy	5,829	183	540	4,136	10,688
8	Trimming-shop . . .	110	..	..	..	110
9	Carriage-shop	8,825	..	2,495	16,080	27,400
10	Saw-mill	75,838	5,890	10,600	1,693	94,021
11	Paint-shop	1,410	..	140	1,099	2,649
12	Engine-room	43,772	..	6,266	..	50,038
13	Workshop yard . . .	7,999	..	561	1,378	9,938
14	Total	7,01,293	40,336	88,942	99,885	9,30,456
15	Estimated further expenditure for complete equipment	55,407	3,164	7,258	3,415	69,544
16	Grand total for complete equipment	7,56,700	43,800	96,200	1,03,300	10,00,000

(*Paper No. 3102.*)

"River Regulation Works, and Harbour and Canal Construction in Germany."

By LUDWIG FRANZIUS and GEORGE HENRY DE THIERRY.

DURING the past twenty years great activity has been exhibited in Germany in regard to works for the regulation of rivers, and the construction of harbours and canals. The Authors propose to describe several important examples of such works, which may be regarded as typical of their general character.

BREMEN AND BREMERHAVEN.

Bremen is situated 74½ miles above the mouth of the Weser.[1] Up to the 16th century the ships of the period could get up to Bremen; but, as the draught of vessels increased, the port of access had to be gradually shifted lower down the river. Eventually, in 1827, Bremen acquired land for a port to the north of the River Geeste; and the first dock built at Bremerhaven, opened in 1830, is connected with the Weser by a lock 36 feet wide and having a depth of 18 feet of water on its sill, Fig. 1, Plate 5. The gates of this lock are arranged so as to sluice the entrance. The second dock, called the New Dock, was built in 1851, with an entrance 62 feet wide and 24 feet deep. The third dock, the Kaiser Dock, was opened in 1876; it has an entrance 56 feet wide and 25 feet deep, and is connected with the New Dock by a passage 52 feet in width, Fig. 1, Plate 5. In spite of these extensions, the trade of the ports of Bremen only increased slowly; while that of the neighbouring ports of Hamburg, Amsterdam, Rotterdam, and Antwerp, progressed materially, partly owing to better communications between these towns and the sea, and partly to canals connecting them with the surrounding country.

To maintain its position in the markets of the world, Bremen, with a population of only 150,000, had to seek to improve its

[1] "Neuer Hafen zu Bremen," by L. Franzius. Fortschritte der Ingenieur-Wissenschaften. "Seekanäle, Strommündungen, Seehäfen," by L. Franzius, G. Franzius, and R. Rudloff.

communication with the sea by the regulation of the Lower Weser, which, according to the scheme prepared by Mr. Franzius in 1879–81, involved an expenditure of £1,500,000. The proposed port at Bremen was barely equal to the requirements of the time; and the entry of Bremen into the Customs' system of the German Empire in 1884, necessitated the provision of a free port completely shut off from the rest of the port and town, at a cost of £1,500,000, towards which £600,000 were contributed from the imperial exchequer. The port of Bremen is chiefly intended to accommodate the European traffic, Fig. 2, Plate 5; whilst the large transatlantic steamships, and in particular those of the North German Lloyd, use Bremerhaven.

As the available depth over the sills of the entrances to the New and Kaiser Docks at Bremerhaven is inadequate to ensure the entrance at high water of the vessels of increased draught of the present time, involving sometimes a delay of days, the Bremen authorities decided, in 1891, to construct a new entrance for the larger steamships in connection with an enlargement of the Kaiser Dock, Fig. 1, Plate 5. The cost of the extensions of the port are estimated at £925,000.

Free Port of Bremen.

A free port, in which goods subject to duty can remain in bond, must be completely shut off from the surrounding country, and all outlets carefully guarded. The laden ships pass up and down between the harbour and the sea under control of the Customs, but are free in the port; and all goods passing out of the port to the town have to pay duty. There was a very convenient site for the port on the right bank of the Weser, unoccupied by buildings, with a good subsoil, and offering an easy embayed entrance down-stream. The free port has an area of about 247 acres, with a maximum length of 8,200 feet, and an average breadth of 1,300 feet, Fig. 2, Plate 5. The general arrangement of the port, determined by the form of the site, consists of a large dock 6,560 feet long, with railways, streets, warehouses, and grain-stores, arranged nearly symmetrically on either side. At the upper end, the lines of dock railway branch off from a single line of the connecting railway; and, at the lower end, the entrance narrows to 197 feet—half the normal width of the dock—to prevent, as far as possible, the deposition of sand from the Weser. Although there is a difference of 23 feet between highest water-level caused by land floods and low water in the Weser, an open

dock was preferable to a closed one, because, owing to the long period of slack water in the river and the porous character of the subsoil, the water-level in a closed dock would not have remained independent of that in the river, but would have varied about 13 feet.

Bremen Dock.—It was at first intended to excavate the dock to $22\frac{1}{3}$ feet below Bremen zero (ordinary high water rises to 2 feet below, ordinary low water falls to about 6 feet below Bremen zero); but the depth was increased in 1893 to $26\frac{1}{4}$ feet, owing to the fall in the low-water level of the river which occasionally falls to 10 feet below zero, Figs. 3 and 5, Plate 5. Quays surround the dock, with massive moles at the entrance, Fig. 2, Plate 5; and 12,300 feet of quays are founded on piles, and 7,545 feet, bordering on the river, rest on concrete between sheet-piling. The walls on piles are given a sufficient width to contain a tunnel large enough to allow a man to pass through, and to give them adequate strength to withstand blows from vessels, Fig. 3, Plate 5. The large quantity of material required by this arrangement, is compensated for by the use of cheap concrete filling in spaces left in the centre of the brickwork, consisting of one part of cement to ten parts of gravelly sand, which, having a greater specific gravity than brickwork, renders the wall more stable than if bricks and mortar alone were used. The tunnel in the upper part of the wall contains the hydraulic and electric mains. A small railway also for the transport of heavy pipes is laid along it; and the tunnel communicates with the surface by a number of shafts, and large end openings. As the hydraulic mains are filled with warm water from the condensers of the engines in winter to prevent freezing, the temperature of the tunnel is fairly uniform. Fender piles, strongly anchored and with iron heads, are placed against the wall about 33 feet apart, and serve also as bollards. Mooring rings and iron ladders are, moreover, provided; and massive stairs communicate with the water.

Sheds, Warehouses, and Appliances.—The fronts of the quay-sheds, which are for the most part 131 feet wide, are entirely closed by galvanised corrugated-iron sliding doors, so that several hydraulic cranes can be worked together, and the vessel can be unloaded from several holds at the same time. A shed can therefore be entirely closed or opened on the water side; and, on the land side, access is given by doors, between each two of which a crane is placed. These sheds are surrounded by loading stages; and, in order that the cart traffic may be kept separate from the railway traffic, they are arranged so that vehicles may drive in under them from the street; and nine may at one time be

conveniently loaded from the floor-level, which is the same as that of the loading stages, Fig. 3, Plate 5. Besides this, the warehouse fronts serve the vehicular traffic. On the rebuilding of one of these sheds, which had been completely destroyed by fire in a short time, it was divided up by two fire-proof walls. The total length of quay-sheds already built amounts to 5,052 feet, and they have a total area of 724,800 square yards. For unloading and storing cargoes of cotton, there is a shed on the north side of the dock, the floor of which is at street-level on the water side, and rises gradually to the level of the loading platforms on the land side. This shed, built of wood and corrugated iron, and roofed with roofing paper, differs from the others, which are built of iron. Behind this shed is a storage warehouse, which is built in a similar manner.

At first no special means were provided for unloading and storing grain; but owing to the development of the grain traffic, two grain-warehouses were erected in 1896–97. One warehouse on the quay, 558 feet long and 135 feet wide, has only one storey for the first third of its width towards the water side, while the remaining two-thirds are two storeys high. At the back of this warehouse, and separated by a street 66 feet wide, down which lines of railway pass, is a two-storey warehouse, 886 feet long and 98 feet wide. The upper floors of both warehouses are intended chiefly for grain in bulk. The grain in bulk is unloaded from the ships by travelling cranes with grab buckets into automatic balances upon the loading platform, which runs round the whole warehouse. The grain can then either be filled into sacks on the loading platform, or can be transported by travelling bands to any part of either warehouse. Two collecting bands, placed in a tunnel under the floor along the water side of the warehouse, are connected with the elevators working in a special tower built in the centre of the warehouse front. The discharging shoots of the elevator are so arranged that any elevator can deliver on to any one of the four longitudinal bands. From these longitudinal bands, the grain may be either delivered direct into hoppers, to be directly placed in sacks, or it may be delivered on one of the four distributing travelling bands which pass at right angles to the water front across the upper floor of the front warehouse, and through a closed bridge across the street, to the upper floor of the warehouse behind. The grain can be thrown off the bands at any point, and either placed in sacks or stored in bulk. The elevating and distributing machinery is driven partly by gas-engines, partly by dynamo machines having a total of 60 HP. The warehouse

on the quay covers an area of 7,940 square yards, and the storage warehouse 6,110 square yards. They can store 18,000 tons in a manner usual for a lengthy period, and 12,000 tons for the time usually adopted for grain in towns. The machinery was supplied by G. Luther of Brunswick; the total cost amounted to about £56,100.

At each entrance to the warehouses, the different floors of which are served direct by the street cranes, is a hydraulic lift, and also a hydraulic windlass at the back. Behind the warehouses are lines of railway, of which the two nearest are sidings, and the remainder serve the general traffic of the dock. The six warehouses already erected have a ground-floor area of 23,460 square yards, and a total floor area of 111,330 square yards.

At the upper end of the port, where the quay becomes too narrow for regular sheds and warehouses, repairing shops for railway wagons and shunting locomotives, and a fire station are placed on the left side; while hard woods are stored in the open, and under sheds on the right side. Narrow-gauge railways intersect these shops and yards, which are provided with special wagons and cranes, and the sheds with lofty travellers. On the left side of the mouth of the dock there is a place for repairing ships, and a large double floating dry dock. On the opposite side there is a coal-tip dealing with 15-ton coal-wagons, which is arranged to lower as near the vessels as possible. A large shoot, carried by special arms, breaks the fall of the coal. The empty wagons are lifted by hydraulic power, being turned simultaneously through an angle of about 90°, and travel down a gradient to a collecting siding.

Hydraulic Plant.—There are eighty-five cranes, with a total lifting capacity of 1,512 tons (seventy-four being movable and eleven fixed), fifty lifts and windlasses in the warehouses, and seventeen windlasses between the lines of quay railway. All these cranes, &c., are worked by water at a pressure of 711 lbs. on the square inch. The machinery house is at the upper end of the port, containing three vertical steam-pumps, each of 100 HP., making 60 revolutions per minute, and furnishing 2,047 cubic feet of water per hour. Close to the pumps are two accumulators, having a capacity of 209 gallons each. The speed of the engines is governed by one of the accumulators, and indirectly by the amount of water consumed. The pumps take their water from high-level tanks fed by the cooling water from the surface condensers. The cast-iron hydraulic pressure main is 5 inches in diameter, and has a length of about 3¾ miles. Most of the cranes,

lifts, and windlasses are fitted with three powers, which renders it possible, within these three powers, to make the consumption of water correspond with the weight lifted. The form of the cranes was chosen to occupy as small an area as possible, and to give the driver a good view of his work. The carriages are rectangular, and rest on four wheels, two of which run upon a rail fastened to the coping of the wall; whilst the two inner wheels run upon a rail fastened to a girder carried by the sheds on the quay, Fig. 3, Plate 5. The space under the crane carriage is sufficient for two lines of railway, and for the 7½-foot wide loading-stage. The levers controlling each crane are all placed in a small house high up on the water side, whence the drivers have uninterrupted views. The travelling cranes are connected with the hydraulic main by flexible pipes 16 feet long and have a lifting capacity varying between 1½ ton (by sixty-eight cranes) and 10 tons. The windlasses, situated between the lines of quay railways serving to move the railway wagons and travelling cranes, are capable of exerting a pull of 1 ton. All the cranes and lifts in the warehouses have a lifting capacity of 1½ ton.

Electric Light.—The four dynamos in the machinery-house are driven by two steam-engines of 200 HP. each. A 90-HP. battery of accumulators relieves the engines when they are pressed, and entirely supplies the system with current during slack times. One of the engines and the battery working together have a capacity of 3,200 16-candle lamps. Arc lamps are used in the open, and one is placed on each crane on the water side of the sheds.

Floating Crane.—A floating crane is provided for lifting very heavy weights, with two powers, one capable of lifting up to 40 tons and the other up to 10 tons.

Landing-Stage.—At the upper end of the port there is a pontoon landing-stage for the small passenger steamboats plying on the Lower Weser, which is connected with the quay by a bridge.

Timber and Manufactories Dock.—To the north of the Bremen Free Dock, and inside the Customs' barriers, is the timber and manufactories dock, on one side of which are timber yards let to private firms, and on the other two large steam-mills, an oil manufactory, and a large warehouse. Both sides of this dock are connected with the railway. As the Bremen harbour installations are already insufficient for the traffic, it is proposed to commence at once constructing a second dock between the Timber and Manufactories Dock and the Free Dock.

THE REGULATION OF THE LOWER WESER.[1]

The Weser is formed by the junction at Münden of the Werra, rising in the forest of Thüringen, and the Fulda, coming from the Rhön and the Vogels Mountains. The Upper Weser, between Münden and Bremen, has a length of 227 miles, and drains 16,000 square miles. The river between Bremen and Bremerhaven is known as the Lower Weser, having a length of 42 miles; and the Outer Weser extends from Bremerhaven to the sea, Fig. 4, Plate 5. The two last portions of the Weser drain 2,550 square miles. The area of the river increases rapidly towards its mouth. The Upper Weser, in spite of its greater length, has an area of only 8,150 acres; the Lower Weser covers 16,300 acres, and the Outer Weser 133,000 acres. The area accordingly of the tidal portion greatly exceeds that of the remainder. The fall of the Upper Weser, which in places reaches 1 in 300, decreases generally downstream from 1 in 2,100 to 1 in 6,500. The discharge of the Upper Weser into the tidal portion varies between 3,510 cubic feet per second at lowest summer level and 111,200 cubic feet per second at highest observed flood-level. Even the greatest fresh-water discharge is small in comparison with the mean tidal volumes at the mouth opposite Bremerhaven, which during an average tide amount to 1,977,000 cubic feet. Before the regulation of the river, the tide only ascended a little above Bremen; and with an average river flow of 5,290 cubic feet per second, the rise of tide was as follows:—at Bremen 0·00 feet, Hasenbüren 0·85 feet, Vegesack 2·98 feet, Farge 6·39 feet, Brake 10·30 feet, Bremerhaven 10·82 feet. The average rise of tide at the Red Sand Lighthouse, about 28 miles below Bremerhaven, is 8·79 feet, and it decreases at Heligoland to 6·03 feet.

Design of Weser Regulation Works.—Before the regulation, the bed of the Lower Weser was very irregular, Fig. 5, Plate 5. For $13\frac{1}{2}$ miles out of a total length of $31\frac{1}{3}$ miles between Bremerhaven and Vegesack, the river was split up by islands and banks dry at low water, Fig. 4, Plate 5. The worst part was between Brake and Vegesack, where, owing to the nearly continuous obstructions dividing the river and its too great width, the velocity of flow decreased rapidly, especially with high water in the river, which

[1] "Die Korrektion der Unterweser," L. Franzius, Bremen, 1888; "L'Amélioration des Fleuves dans leur partie maritime," L. Franzius, Vme Congrès International de Navigation intérieure, Paris, 1892; and Minutes of Proceedings Inst. C.E., vol. cxviii., pp. 33-35, and Figs. 25-32, Plate 3.

allowed the debris swept down through the artificially narrowed passage between Vegesack and Elsfleth, to settle and form a bar. While this constriction materially raised the up-stream water-level, the bar retarded the tidal flow, so that the volume of the flood-tide was reduced, its speed and duration decreased rapidly, and the tidal condition was unsatisfactory.

The regulation works, giving an available depth of 16½ feet in place of 9 feet, were designed to increase and guide the scour of the current, so that the improved channel might be easily maintained. The data governing the design were the tide-tables and tidal lines obtained by self-registering tide gauges along the river. It was necessary to do away with all curves, irregularities, and especially divisions of the river, so as to retard the progress of the flood-tide as little as possible. The cross-sections of the regulated river channel are so proportioned as to be always large enough to allow the flood-tide to pass freely up; and they increase in area downstream in such a way that there is no decrease in velocity which might tend to the formation of bars. The estimated high- and low-water levels were fixed as the basis of a depth of water sufficient for ships drawing 16½ feet, retaining the previous tidal volume at Bremerhaven and the tidal limit above Bremen. Starting from Bremerhaven, the new flood-tide lines were determined by these data, and Scott Russell's formula for the tidal progress, $C = \sqrt{g\, h}$; where h is the momentary depth of water on the length in question. The ebb-tide lines were determined by analogy from previous tidal lines.

These tidal lines, in conjunction with the estimated width at the water-level after the regulation, enabled the tidal volume between any two gauging stations to be determined. In the length between two stations, the volume flowing in or out equals the area at the water-level multiplied by the rise or fall. These totals, calculated from hour to hour after high and low tide, added together, with the fresh-water discharge from the upper river, gave the total volume flowing through each lower cross-section. Since the volumes, sectional areas, and velocities depend upon each other, and change continuously, an average velocity for a whole tide must be fixed for each station, in order to determine a corresponding cross-section. These average velocities were determined with reference to the debris to be carried forward by the current. The calculations with different coefficients: volumes, cross-sections, and velocities, were repeatedly made, with the help of diagrams, until, by inserting fresh probable values, an agreement between all the results was obtained. The probable low-

water surface fall was also calculated, and compared with that then existing. After the determination of these factors, the section of the river-bed and position of the banks were determined. The low-water cross-section of the river-bed was designed quite distinct from the high-water cross-section. By the separation of a uniform low-water channel, made as small as shown by the calculations to be allowable, and a high-water channel left as large as possible, on the one hand a regular and undivided flow was secured, and on the other hand storage for tidal waters, which increase the ebb flow in the low-water channel, and materially help to keep it clean. Economy in cost was the governing factor in determining the boundaries of the low-water channel, the boundaries of the high-water channel being for the most part allowed to remain unaltered. The low-water channel was made to follow the old channel as far as possible, which necessitated unsymmetrical cross-sections in some parts. The location chosen required the removal of 71,941,000 cubic yards of material; whereas symmetrical cross-sections would have necessitated the removal of 139,958,000 cubic yards.

The low-water channel was fixed by training walls, the tops of which were to be little above average low-water level; and the material dredged from the channel was deposited on the space between the walls and the old bank. On the completion of the whole design, the correctness of the various proportions were tested by calculating the surface fall at low-water, to determine whether the assumed low-water line might possibly be lower than that then calculated. The comparisons showed that the calculated fall was greater throughout, so that it might be anticipated that the low-water line would fall lower than assumed, and, consequently, that the effect of the regulation would be greater than was laid down in the design.

Construction of Lower Weser Regulation Works.—Between 1883 and 1886, the "Lange Bucht," a sharp curve just below Bremen, was trained, which materially improved the navigation, and enabled ships drawing 10 feet to reach the town from the sea in a single tide under normal conditions.

Negotiations with the States of Oldenburg and Prussia, through which the river flows below Vegesack, having been concluded in 1887, and the estimated cost of the regulation, £1,500,000, voted, the works were commenced in July, 1887. The plant for the regulation of the Lower Weser consisted of eight ladder-dredgers, two of which are capable of raising 330 cubic yards per hour. For the transport of dredged material, there were fourteen steam-

barges, with a capacity of 130 cubic yards, eight of 260 cubic yards, and sixty barges of 45 cubic yards and 52 cubic yards capacity, served by five steam-tugs. So long as there was sufficient depth behind the training walls in the side branches and in the neighbouring inlets, the excavated material was deposited straight from the barges; but as these areas gradually became too shallow, two kinds of secondary dredgers were introduced in 1890, which raise again the material deposited by the barges, and force it through pipes to a distance of from 450 yards to 550 yards. In one of these dredgers, the lifting and depositing apparatus are both on one vessel; while in the other, three dredgers the depositing apparatus is on a second vessel.

Between 1887 and 1894, about 36,625,000 cubic yards were dredged, 34,009,000 cubic yards of which were taken from the channel, and the remainder from inlets and ditches draining the neighbouring land. Of the total quantity dredged, 27,468,000 cubic yards were deposited direct behind the training-walls and in the side branches; while about 8,502,000 cubic yards were taken to the dredgers with pipes and spread over the shallow flats, and the remainder was used as ballast, &c. By the end of 1894, $22\frac{2}{3}$ miles of training-walls and $9\frac{1}{3}$ miles of cross-walls and dams had been constructed along the Lower Weser. The work was then so far completed that the designed effective depth of $16\frac{1}{2}$ feet had been attained, Fig. 5, Plate 5; and the Chancellor of the Exchequer of the German Empire granted Bremen the right to levy tolls upon ships passing the regulated part of the Weser.

The effective depth attained in successive years was as follows:—1886, 9·8 feet; 1887, 9·8 feet; 1888, 11·4 feet; 1889, 13·1 feet; 1890, 14·1 feet; 1891, 15·0 feet; 1892, 15·7 feet; 1893, 16·4 feet; 1894, 16·4 feet.

The number and tonnage of ships using the channel, drawing $14\frac{3}{4}$ feet to $16\frac{1}{2}$ feet and over, were:—

Year.	Draught $14\frac{3}{4}$ to $16\frac{1}{2}$ Feet.	Draught $16\frac{1}{2}$ Feet and over.	Total Registered Tons.
	Number.	Number.	
1891	1	2	317,006
1892	22	..	433,164
1893	51	4	521,607
1894	115	47	641,382
1895	191	71	651,976
1896	205	94	648,448
1897	511	122	723,000

with an increase of 126,000 registered tons for the year 1898.

The improvement works, however, were by no means terminated in 1894; for though little was done in subsequent years to the regulation works beyond their maintenance, the dredgers were employed, working short time, in increasing the sectional area of the channel to the extent laid down in the design. In 1895 3,662,000 cubic yards were raised; in 1896 2,354,000 cubic yards; and in 1897 1,962,000 cubic yards, being small amounts in comparison with the 5,886,000 cubic yards dredged in 1891.

Effects of Lower Weser Regulation Works.—Besides the practical results of the regulation, indicated by the increase of the number of ships of deep draught, the following effects deserve notice. The volume of water entering and leaving the river has materially increased, particularly in the upper part. For example, the volume near Farge, with a fresh-water discharge of 5,290 cubic feet per second, was 13,800 cubic feet per second before the regulation, with an average velocity of 1·08 foot per second; in 1897 the volume per second amounted to 22,000 cubic feet, with an average velocity of 1·54 feet per second. According to the design, the volume of water should be 35,000 cubic feet per second, the average velocity 2·43 feet per second; and it is certain that this volume will be reached when the cross-sections have attained the intended dimensions throughout. As was expected, equinoctial flood-tides have not yet risen higher up the river than before the regulation; but, on the other hand, the discharge of flood-water from the river has been materially accelerated. Before the beginning of the regulation, it was feared by the riverside population that, owing to the increased volume of the flood-tide, the salt water would rise higher up the river, and that consequently the customary admission of the water of the Weser through the marshland dikes, for the use of cattle during times of drought, would be impossible or dangerous to the animals. To meet this objection, Bremen was forced, before the works began, to pay £123,900 to the Archduchy of Oldenburg for the construction of an inland canal. Investigations since 1887, of the amount of salt in the water taken below the surface of the Weser at different points, show that little change has taken place in the salt-water limit.

Before the regulation, the Weser froze fast nearly every winter between Bremen and Vegesack; but the regulation has rendered the formation of ice more difficult, by increasing the volume and velocity of the current. To maintain the passage in severe winters, three steam ice-breakers, two of 200 HP. and one of 1,000 HP., traverse the Lower Weser twice daily when necessary.

They are of the usual beam form with sharply-curved bows, and have water-ballast in the stern, which is arranged for steaming backwards in the ice; and they have answered well. The cost of the regulation up to the 31st March, 1897, amounted to about £1,450,000.

THE REGULATION OF THE OUTER WESER.[1]

In 1891, when the regulation of the Lower Weser between Bremen and Bremerhaven was partly completed, the States of Prussia, Oldenburg, and Bremen commenced an improvement of the Outer Weser below Bremerhaven, from the design of Mr. Franzius, Fig. 4, Plate 5. The first work, consisting chiefly of two training-walls, was designed for the removal of a bar, caused by a division of the current, which had existed for about 30 years, and had finally attained a length of nearly 7 miles, Fig. 5, Plate 5. One training-wall on the left bank, about 4⅓ miles in length, was built in 1891–92; and the second training-wall, 1 mile long, was built on the right bank, between Imsum and Wremen, Fig. 4, Plate 5, reducing the excessive breadth of the river, and effecting the removal of a large quantity of material by the scour of the current. In a length of 12 miles, over 11,772,000 cubic yards were removed in 2 years, of which, however, 4,708,000 cubic yards only changed their position. In 1893–94, the current scoured nearly 10,464,000 cubic yards from the same length of river, of which only 340,000 cubic yards were again deposited in the channel. With such extraordinary movements of the channel bed, the formation of banks here and there could not be avoided; and in the winter of 1895–96, a sea-going suction-dredger of 500 I.HP. was obtained to keep the channel open to Bremerhaven, particularly for the deep-draught express steamboats. This dredger, aided by the action of the current, has succeeded in keeping the channel open in a fully satisfactory manner. The dredger "Columbus" has a hopper of 1,125 cubic yards capacity, which, under favourable circumstances, it can fill in ¾ hour. Thus the theoretical capacity of the dredger is over 1,300 cubic yards, or 2,000 tons, per hour. Since a shoaling of the channel might take place simultaneously in two spots far distant from one another, or the single dredger might require lengthy repairs, a second dredger was ordered in 1897 for commencing work in the spring of 1898. The hopper of this dredger

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[1] "Projekt für den weiteren Ausbau der Aussenweser," L. Franzius and Bücking, Bremen, 1895.

can contain 1,300 cubic yards; and its capacity for work is 25 per cent. greater than that of the "Columbus."

Lower down, the Weser is again split up by the Robben Plate, the main deep channel being on the right-hand side, Fig. 4, Plate 5. In consequence of this division of the river, and a further branching off between the two sandbanks—East and West Ever Sands—a bar had formed at the north end of the right-hand channel, 11 miles below the first-mentioned bar. As ships of considerable draught could only pass these bars when the tide was high, an extension of the scheme of 1891 has been proposed, consisting of a dam across the branch channel between the East and West Ever Sands, and a contraction of the branch of the river on the left of the Robben Plate by a training-wall and dam, so as to secure a preponderating volume of the tidal flow along the right branch. This branch is sharply curved; and, to prevent further movement in an easterly direction, it is proposed to build training-dams to protect the sandbanks. In 1896, the branch between the East and West Ever Sands, which has a breadth of about $\frac{2}{3}$ mile, was dammed by depositing a layer of weighted fascines, $3\frac{1}{4}$ feet in height; and, in 1897, a second layer was added. Works also were carried out in 1896–97 for the protection of the "Wurster Watt." These works, in conjunction with the small amount of dredging effected, have considerably lowered the bars, so that in 1898 the new North German Lloyd passenger steamer, "Kaiser Wilhelm der Grosse," drawing 28 feet, was enabled to pass over the bars without delay. The object of all these works is to attain a low-water depth of 26 feet throughout, so that vessels of large draught might not be restricted to just before and after high water. The results already secured give promise that this object will be attained in a few years. The estimated cost of the regulation of the Outer Weser, in the designs of 1891 and 1895, was £400,000. Up to the 31st March, 1897, £187,500 had been spent. The three riparian States, Prussia, Oldenburg, and Bremen, share the cost of the works, inasmuch as all dues on ships traversing the Lower Weser are devoted to the service of the money expended, which is provided by Bremen.

Extension of the Port of Bremerhaven.

The Corporation of Bremen determined in 1891 to build a new entrance, and to extend the port at Bremerhaven. The new entrance is about 985 feet long and nearly straight, and terminates in a large lock connecting it with the dock extension, Fig. 1,

Plate 5. It is protected by a projecting mole on the lower side, so that ships can enter or leave quite unaffected by the current. The bank also below the mole, for a length of 656 feet, is built up as a quay above the highest flood-tides, to serve ships which either cannot or do not wish to enter the dock, Fig. 6, Plate 5. Should the need arise, this quay can be extended to almost any extent down-stream, and provided with a line of railway. The dock is capable of considerable further extension laterally. The different lines of railway run in an easterly direction from the dock extension to a small station built in 1891, which is connected with the Bremen-Geestemünde-Cuxhaven lines. The lock and dock extension were opened in 1897. On the north side of the port, a large dry dock is in course of construction, to the cost of which the German empire has contributed, so that when necessary battle-ships can be docked there. The total cost of the works is estimated at £900,000.

New Lock at Bremerhaven.—The chamber of this lock has a length of 656 feet, while the available length between the gates is 705 feet, Fig. 7, Plate 5. The clear width of the entrance was at first intended to be 82 feet, but was finally made 92 feet to meet the wishes of the North German Lloyd. The depth is sufficient to admit battle-ships drawing 31 feet during neap tides. An invert was dispensed with in the lock as unnecessary, since no springs were likely to be found in the stiff clay on which the lock stands, Fig. 8, Plate 5; while a sliding caisson was chosen in place of inner gates, as not only requiring less brickwork, but costing less in itself than gates, and serving in addition as a movable bridge, Fig. 7, Plate 5. The caisson, moreover, could be readily moved for repairs; while the repair of gates is difficult and costly. Little importance was attached to the objection that the caisson chamber would be very liable to silt up, since the movement of the caisson in and out would create currents which would tend to keep it clean, which could be readily assisted by artificial means. A sliding caisson was not used in place of the outer gates, as the new entrance was intended to be used as a lock only between low water and the time when the water in the Weser reaches the level of that in the dock. During this period the express steamers and other vessels of large draught were to be taken through the lock, so that they might pass the bars, then still existing about 6 miles below Bremerhaven, at the right time. During the remaining period, from the moment when the water in the dock and that in the Weser are at the same level until the water begins to fall, lasting on an average about 2½ hours, the

lock was to stand open; and all entering, and the smaller out-going ships, were to pass straight through. Now during spring-tides, a strong current would flow through the lock into the Kaiser Dock, having an area of 49 acres, which during southerly winds would be considerably increased by the heaping up of the tide on the Bremerhaven shore; and this current, aided by the force of the waves and the pressure of the wind, might exert a lateral force which could not be so well resisted by a sliding caisson, supported at one end only, as by two strong gates.

The lock chamber has a breadth of 147 feet, so that the largest passenger steamers can lie there preparatory to starting, and receive cargo from lighters. The walls in which the lock sluices are built, like the walls along the entrance channel, Fig. 6, Plate 5, are founded on piles, none of which are driven vertically, but in rows, 4 feet apart, inclined alternately in opposite directions, Fig. 8, Plate 5. This arrangement secures a favourable distribution of the forces acting on the piles, and has the further advantage that the pile-heads are not so near together, and the piles can consequently be driven deeper into the solid ground, because the compression extends over a greater area than would be the case with vertical piles. The iron gates are actuated by hydraulic power; and, in order that the power required may be always the same, and the strain on the hinges as small as possible, the water is allowed a free passage through the upper part of the gates.

A small basin communicates with the dock by an entrance, which is crossed by an iron swing-bridge, for railway wagons and carts; and this basin leads to a dry dock sufficiently large to receive ships up to 656 feet long and 82 feet wide. The dry dock sill is 23 feet below the zero at Bremerhaven, where ordinary high water reaches $+ 11 \cdot 68$ feet and ordinary low water is $+ 0 \cdot 85$ foot; and, with a comparatively low water-level in the dock of $+ 9 \cdot 2$ feet, ships drawing 31 feet can be docked. The bottom of the dock is formed of concrete deposited under water, and the walls are built of cement concrete with a brickwork facing. The walls also are strengthened where necessary by the introduction of blocks of granite. The dock is closed by a floating caisson, which can be placed either at the end, or 197 feet from the end to economise pumping in the case of small vessels. Three centrifugal pumps are provided, which, with a water-level of $+ 11 \cdot 68$ feet in the dock, corresponding with the average high-water level in the Weser, can empty the dock in 2½ hours. A repairing dock is placed near the dry dock, where one ship

656 feet long, and another 490 feet long, can lie conveniently. This dock is intended for ships which do not need to be laid dry, and to complete the repairs to ships from the dry dock. The graving dock and repairing dock are provided with electric cranes, and are connected with the railway system of the floating dock. The cost, to which the Empire has materially contributed, is about £250,000.

The Red Sand Lighthouse at the Mouth of the Weser.

The Red Sand Lighthouse was built in 1883 to guard a bank at the mouth of the Weser, 29 miles below Bremerhaven, and to supplement the lighting of the German North Sea coast. The structure was founded by compressed air, which enabled a massive substructure to be built without the aid of temporary staging; as it was feared that screw piles might be destroyed by the shock of drifting ice, like the Hooper Lighthouse in Chesapeake Bay in 1877. The caisson, 46 feet by 36 feet and oval in plan, was built at Bremerhaven, towed to the site, anchored, and sunk by the admission of water, in a depth of 26 feet, Fig. 9, Plate 5. The caisson had a height of 61 feet and a draught of 21 feet; and weighted fascines were at once laid around it to prevent scour; and in order to give it stability, it was filled as soon as possible with concrete, in which part of the sand excavated was used. The foundation of concrete and masonry was carried up to 5·7 feet above zero; and from this level to + 26¼ feet, the base of the tower is encased in cast iron, and has a diameter of 33 feet 9½ inches at the bottom and 21 feet at the top, and is filled in with masonry, and contains two cisterns. From the level of + 26¼ feet upwards, the tower consists of twelve strong wrought-iron legs, stiffened by the various floors and covered with plates ⅜ inch thick. The living rooms and kitchen are protected from changes in temperature by wooden casings. In 1896 the lighthouse was connected by an electric cable with the island of Wangeroog, and since then electricity has been used for the light. A self-registering tide gauge records the variations in water-level. The lighthouse was built by the Aktiengesellschaft Harkort, of Duisburg, at a cost of £42,650, exclusive of the lighting apparatus. An attempt had been made in 1881 to build a lighthouse on this spot with the same system of foundation, but on October 9, 1881, a storm stopped the work. The caisson had reached a depth of – 68 feet, or only 4 feet less than the full depth; and the iron casing had been filled to about the level of the bottom of the sea, but the upper

part, about 40 feet in height, was empty. The storm broke this part about 8 feet above ground-level, probably owing to the waves breaking over the caisson and destroying the wooden supports inside. In the existing structure, strong iron vertical and horizontal stiffeners were substituted for the wooden supports; and the casing was raised to + 35 feet, the top 30 feet being afterwards removed.

PORT OF HAMBURG.[1]

Hamburg is about 62 miles above the outlet of the Elbe into the North Sea, and is the greatest port on the Continent. The average rise of tide is about 5·9 feet, but the maximum difference between high and low water reaches 19·7 feet. The effective depth of the channel is about 23 feet, so that nearly all ships can reach the town at high water. Up to 1866 all sea-going ships were moored to dolphins, arranged in long rows in natural bays and in the stream. The traffic between the ships and the warehouses was carried on by open barges which traversed the numerous canals intersecting the town. The Sandthor and Grasbrook basins were constructed on the right bank of the Elbe between 1860 and 1870, Fig. 10, Plate 6. Open basins were adopted because the Elbe near its tidal limit leaves little deposit, and the depth of water in front of the town allowed ships to pass in and out between the port and the roadstead in the river at any time, and because locks would have seriously hindered the considerable traffic between sea-going ships and the river-boats which ply between Hamburg and Bohemia.

Extension of Port.—The decision of Hamburg, in 1881, to join the Customs' system of the German Empire necessitated material alterations in the port. Some of the warehouses in the town were made bonded warehouses, and the port remained a free port. Owing to these changes and the growing needs of the sea and river traffic, a period of great activity in the extension of the port began in 1884. On the right bank the Beacon Basin, Fig. 11, Plate 6, and on the left the sailing-ships', Hansa, India, Petroleum, Moldau, Saale, and Spree basins were constructed, Fig. 10, Plate 6; so that ships passing from the Upper Elbe to the Lower, or *vice versâ*, which do not want to enter the free port, may suffer

[1] "Hamburg und seine Bauten," Architekten- und Ingenieur-Verein zu Hamburg, 1890; Centralblatt der Bauverwaltung, 1897, p. 335; "Erweiterung der Hamburger Hafenanlagen," by F. Bubendey; Proceedings of the International Engineering Congress in Chicago, 1893, Part I., p. 173; "Die Entwickelung der Ufer-Krane im Hamburger Hafen," by Chr. Nehls.

as little hindrance as possible, and yet may be properly controlled by the Customs. The Upper Basin Canal, the Customs' Canal, and the Inner Basin are excluded from the free port, round which they provide a passage, which necessitated a cut 656 feet long through houses at the upper end of the Inner Basin, costing £2,000,000. This connecting passage, or "Customs' Canal," is only separated from the lower part of the free port by dolphins and floating barriers. Including the river, canals, and side basins, the total area of the free port is 941 acres, of which the basins for sea-going ships occupy 328 acres, and those for the river vessels 135 acres. In 1894 there were 14½ miles of quay for sea-going ships; while of the 11½ miles of bank, 9¾ miles had quay walls. The trade of Hamburg has so increased that the existing facilities are insufficient, and a large extension has become necessary. For this extension, the greater part of the Kuhwärder lands to the west of the free port will be taken, on which four new basins will be built, lying north-west and south-east, leading out of a common outer basin lying nearly north and south, Fig. 10, Plate 6. Of these new basins, the second, counting from north to south, intended for sea-going ships, and the fourth for river vessels, are to be built first. The depth of the basin for large vessels will be 24 feet at average low-water level, and 30 feet at average high-water level; and for the fourth basin, for river vessels, a depth of 12½ feet below low water will be sufficient. The lower or easterly end of these basins will be connected by locks with the Reiherstieg, an off-shoot of the Elbe. The river vessels will thus be able to reach the upper part of the roadstead without passing the entrance to the basin for sea-going ships. The cost of these works is estimated at £550,000.

Of the existing basins, the arrangements of the Beacon Basin are the most complete. Near the quay walls two lines of railway are laid, upon which travelling cranes run between the ships and the warehouses, constructed like those first adopted at Bremen, so as not to interfere with the railway traffic, Fig. 11, Plate 6. The breadth of the basins vary, the basin for sailing ships being the widest, averaging 820 feet. It contains two rows of dolphins, near which, and also in the middle of the basin, numbers of sailing ships can lie and unload into river vessels and barges.

The Petroleum Basin is intended for the use of ships carrying inflammable materials, Fig. 10, Plate 6. Near its entrance the sloping banks have timber-loading quays surrounded by close piling; and on the top come first the lines of railway, and behind them timber sheds, with their floors 2 feet below ground-level.

On the west side, the petroleum tanks stand within a special enclosure capable of containing the whole contents of the tanks plus 10 per cent. The whole area of the Petroleum Basin is fenced in and surrounded by a ditch. The entrance to the outer harbour, and thus the entrance to the Elbe, is carefully secured against fire, by pontoons drawing 2½ feet of water, defended on the harbour side and at their ends by an armour of fire-proof stones.

Sheds, Warehouses, and Appliances.—The sheds on the quay, where the sorting of the unloaded goods is generally done, are one storey high throughout; they are closed on the land side and open to the water. On the land side there are four or five lines of railway, on the two first of which trucks stand to be loaded. The goods unloaded from the sea-going ships, which are to be forwarded by rail, are dealt with on the land side of the sheds; while those to be sent to warehouses in the town by barge are dealt with by cranes on the water side. The water side is paved throughout, forming a roadway for vehicles. With the exception of those on the Sandthor quay, all sheds are built of wood and roofed with roofing paper. The Sandthor quay sheds have stone walls on the land side, and are roofed with iron. Up to 1894 the total length of the quay sheds amounted to 4⅗ miles, with a total covered-in area of 206,300 square yards. The breadth of the sheds varies between 48 feet on the Sandthor quay, and 110 feet on the Asia quay.

In place of the numerous warehouses in the town, which, after the entry of Hamburg into the general Customs' system, were no longer available, numbers of new buildings have been erected within the free port. Up to 1889, these covered an area of 43,600 square yards; they are mostly 92 feet high, and contain a storage area of 240,000 square yards, offices covering 27,600 square yards, and space used for other purposes amounting to 30,400 square yards. The hydraulic machinery station by the Sandthor Basin can supply 70⅔ cubic yards of water per hour at a pressure of 711 lbs. per square inch, sufficient for 260 windlasses and fifty lifts in the warehouses, and thirty-six cranes including the reserve. In 1893 the cranes on the quays numbered 421, with a total lifting capacity of 1,000 tons, 66 being fixed and 355 movable.[1]

When a large number of ships arrive at Hamburg, the interchange of goods is between either sea-going ships and river vessels plying on the Upper Elbe, or barges by which goods are conveyed

[1] Proceedings of the International Engineering Congress, Chicago, 1893, Part II., p. 259.

to warehouses along canals intersecting the town. In these cases the ships are usually moored to dolphins, which consist of clumps of three, nine, or thirteen piles driven 13 feet to 16 feet into the ground and well braced together, so that, while elastic, they are sufficiently strong. A number of the dolphins in the river are protected by ice-breakers.

Landing-Stages.—The arrangement of the port on both banks of the Elbe, and the existence of large shipbuilding yards, factories, &c., on the left bank, produce a large traffic between the two banks of the river, which is served by steam ferries. Special landing-stages are provided for the use of these ships and for the large river steamers which also carry passengers. The rise and fall of the tide necessitated floating piers, which are connected by gangways with the bank, or can be reached at any state of the tide by steps in the quay walls. The remaining steam-ferry traffic is served by wooden rafts supported on empty petroleum barrels, or in the most important situations by iron pontoons decked with wood, or concrete on iron plates. The interior of the bigger pontoons against which the larger river steamers lie, is high enough to afford space for store- and waiting-rooms. The most important of these is situated in front of the St. Paul division of the town, having a length of 656 feet, and is connected with the bank by three bridges. For over-sea passengers, there is a special landing-stage by the strand quay; and close by on the bank there are waiting-rooms for saloon and second-class passengers, connected with the landing-stage by a covered bridge.

Ocean and River Traffic.—The following Table indicates the development of the sea-going trade of Hamburg:—

Years.	Ships Entering.	Registered Tonnage.
	Number.	Tons.
1871–80, Yearly Average,	5,502	2,206,000
1881–90, „ „	7,015	3,870,000
1891–95, „ „	8,928	5,954,000
1895	9,443	6,254,000
1896	10,477	6,445,000

The river traffic exhibits a similar development in the same period, the number of ships entering from the Upper Elbe having increased from 6,081 to 15,978, and the weight of the goods delivered from 492,000 tons to 2,080,000 tons. The weight of the goods despatched to the Upper Elbe has increased from 434,000 tons to 2,969,000 tons. Since 1893, the sea-going trade of Hamburg has exceeded that of Liverpool, the second largest English port.

Cuxhaven Harbour.—With heavy ice in the river, the journey up to Hamburg is not devoid of danger, especially for large ships; while the effective depth of the channel, of about 23 feet, is insufficient for the new express steamers, especially those running to North America. It therefore became necessary to provide a harbour of refuge near the mouth of the river, which at the same time would admit the express steamers at any state of the tide. The position of Cuxhaven, about 62 miles below Hamburg, on an arm of the Elbe having a depth of 112 feet, appeared most suitable for this purpose, because ships could enter at any state of the tide, and the railway connection enabled the voyage of the passengers by the express steamboats to be shortened.

Since the older works at Cuxhaven were insufficient for the new requirements, a small harbour was built for fishing boats behind the dam, 490 feet long, constructed in 1880 for the protection of the bank, and adjoining the old harbour. In addition, a large harbour was built for the steamships of the Hamburg-American line, with an entrance 328 feet wide between the two heads which project in front of the dam, enabling the largest ships to come alongside at all times. The harbour increases in width inside to 820 feet, and terminates in a basin 984 feet long and 263 feet wide, with lines of railway on both sides in direct communication with the Cuxhaven railway-station.

PORT OF STETTIN.[1]

Approach Channel to Port.—Stettin on the Oder is connected by this river with the Baltic Sea, though not directly, for the Oder discharges into the Great and Little Haffs, about 19 miles below Stettin, Fig. 12, Plate 6. These two Haffs together form a bay, 254 square miles in area, separated by the two islands, Usedom and Wollin, from the sea. The middle opening, called the Swine, is the chief connection with the sea, since it serves 181 square miles of the total area. The discharge of the Oder at maximum flood-level reaches 159,300 cubic feet per second; while the range between highest and lowest water-level tide is 6⅓ feet. The range in the Baltic, which is exclusively influenced by the direction of the wind, is 7⅛ feet. With a low stage in the Oder, and high water in the Baltic, water would run from the sea up the river, if the large area of the Haffs, and the comparatively short duration of the storms raising the level of the sea, did not prevent it. In

[1] Zeitschrift für Binnenschiffahrt, 1896, Nos. 2 and 3.

1842 the depth of water between Stettin and the mouth of the Swine was only 12½ feet, which, by straightening the upper curves and dredging, was increased by 1885 to 18¾ feet. In the mouth of the Swine itself, a depth of up to 49 feet was attained by building two moles of unequal length, 1,148 feet apart, at their seaward ends, which increased and guided the current. The most important improvement in the channel to Stettin was the Caseburg Cut, executed in 1877, which not only made the passage between Stettin and the mouth of the Swine easier, but by shortening the course of the Swine materially increased the current through it. The velocity of the current in the Swine entrance was at that time 7·8 feet per second, both in and out; while in the Haff itself, in a depth of 6½ feet, there was no stream at all. Since an effective depth of 18¾ feet was no longer sufficient for the requirements of the port of Stettin, and it became extremely difficult to take the large battle- and merchant-ships, built at the ship-yard "Vulcan" below Stettin, to the sea, a further deepening of the channel to 23 feet has recently been effected. To maintain the channel open in winter, the Stettin merchants and the town acquired three ice-breakers in 1889, which have been completely successful.

Description of Port.—The port of Stettin is formed by the natural waterways, mainly the Oder and its two arms, Dunzig and Parnitz, which branch off in the town, Fig. 13, Plate 6. There are 2,548 yards of quay, of which, however, only a small length is served by lines of railway; and owing to the increase of traffic, and the creation of a free port where goods could be handled out of control of the Customs, the extension in progress was decided upon.

An island, on the right bank of the Oder, formed by the branches Dunzig and Parnitz, was chosen for the site of the new port, for which it was specially suitable, because, besides the possibility of increasing the width of the existing connecting channel between the new port and the river should it become necessary, the proximity of the Breslau station enabled the quay railways to be connected to the main lines. The port consists of an eastern basin, 1,312 yards long and 328 feet wide, near which a second basin, also 328 feet wide, is proposed to be made as soon as the traffic warrants an extension, Fig. 13, Plate 6. Outside the basin there is a wide basin in which ships can turn. The area of the free port is 148 acres, of which 55½ acres consist of water having a depth of 23 feet below mean water-level. The length of quay amounts to 4,720 yards; and the walls are founded on piles,

as a good foundation could only be reached at a depth of 26 feet to 30 feet below mean water-level. A small tunnel was formed in the quay walls, as at Bremen, in which the hydraulic supply pipes for the cranes are placed.

The sheds, standing 39 feet back from the edge of the quay, are one storey high, 597 feet long, and 98 feet deep, and both at the front and back are provided with loading stages. There are two lines of railway on each side of these sheds, and a roadway behind those on the land side, with warehouses on the far side. There is space in the free port for the erection of ten sheds having a total area of 77,850 square yards, and eight warehouses with an area of 37,400 square yards. The loading and unloading of the ships into the warehouses, or into railway wagons, and from the sheds into the warehouses, and *vice versâ*, will be done by hydraulic cranes. The cranes on the water side travel on a rail on the quay wall, and those on the land side on a rail in the roadway; and the second rail is in both cases placed above the doors of the sheds, to gain as much headway under the cranes as possible.

The estimated cost of the port is £1,500,000.

The North Sea and Baltic Canal.[1]

The idea of connecting the North Sea and the Baltic is an old one; but while in the earlier proposals the shortest route was selected, it was laid down in schemes drawn up between 30 and 40 years ago, that more favourable termini must be sought than those of the shortest route. The most favourable points were the mouth of the Elbe on the one side, and Kiel Bay on the other, the former because the depth of water is sufficient for the largest ships, and the latter because it is the second largest German naval dockyard, and the entrance to the canal could be readily defended. Although the canal offers a shorter and a safer route for merchant vessels than the sea-passage, its construction might not have been undertaken for many years to come had it not been for strategic considerations.

Route of Canal.—The canal leaves the Elbe above Brunsbüttel, and passing first through the Kuden Lake, traverses a distance of $18\frac{2}{3}$ miles to the water-parting between the rivers Eider and Elbe, Fig. 14, Plate 6. After passing through the ridge of the river-

[1] Centralblatt der Bauverwaltung, 1886, pp. 233 and 240; 1887, pp. 221 and 229; 1889, p. 73; 1891, pp. 193, 203, and 215; 1893, p. 160; 1894, p. 508; and 1895, pp. 217, 265, 288, 305, and 311.

basins, which rises 75 feet above canal water-level, it follows the tidal part of the Lower Eider. The canal passes $\frac{2}{3}$ mile to the south of the town of Rendsburg, and after touching the Lake of Flemhude, the water-level of which has been lowered 23 feet, follows the Upper Eider and reaches Kiel Bay at Holtenau, at the point where the old Eider Canal entered.

Description of Baltic Canal.—The canal has a length of $61\frac{1}{3}$ miles, of which nearly two-thirds is straight. Since the average rise of the tide at the mouth of the Elbe is 8 feet 10 inches, and the water-level of the Baltic in Kiel Bay varies considerably with the wind, it was necessary to close the ends of the canal by locks, to avoid too rapid currents through it, Fig. 15, Plate 6. The water-level in the canal corresponds with the average level of the Baltic, which differs little from the ordinary half-tide water-level at the mouth of the Elbe. The Baltic locks generally stand open, and are only shut when the water-level rises or falls $1\frac{2}{3}$ feet from the mean. The Brunsbüttel locks are opened during each ebb, and allow the water in the canal, according to the tide, to fall down to $1\frac{2}{3}$ feet below ordinary low-water level; but when this level is reached, they are closed, so as to prevent too strong a current in the canal. The locks are closed during the flood-tide, to prevent the entrance of the Elbe water, which is heavily charged with mud. During each ordinary tide, from 3,924,000 cubic yards to 5,232,000 cubic yards of water flow from the canal into the Elbe, with a maximum velocity of 4·9 feet per second, and clear out the mud and other sediment deposited in the outer harbour by the flood-tide. The bottom of the canal has, therefore, been given a fall to the Elbe for 37 miles.

The depth of the canal, at the lowest water-level, is 27 feet 10 inches; and the breadth at the bottom, on the straight portion, is 72 feet, Fig. 16, Plate 6. To a height of 10 feet above the bottom, the side slopes are 3 to 1; above this they are 2 to 1 up to 23 feet, at which level there is a horizontal berm, varying from 8 feet to 31 feet in width, according to the nature of the ground. The lower parts of the side slopes are made flatter than the upper, with a view to a possible deepening of the canal to $29\frac{1}{2}$ feet. The wetted cross-section of the canal is 454 square yards. The sharpest curve on the canal has a radius of about 50 chains; and the width on all curves is increased according to the formula, $b = 26 - \frac{R}{100}$, where b and R are expressed in metres. There are six passing places for large vessels, each 492 yards long and 65 yards wide.

In constructing the canal, 105,950,000 cubic yards were exca-

vated; and at times 66 excavators and dredgers, 94 locomotives, 582,756 tip-wagons, and 270 tugs and other vessels were at work. The maximum number of men employed was 8,900, in June, 1892. Special difficulties were encountered in cutting the canal through the marshy lowlands, where it was necessary first to tip sandbanks into the marsh, and then excavate the canal through them. At each end, at Brunsbüttel and Holtenau, there are two locks side by side, having an extreme length of 712 feet, an available length between the gates of 490 feet, and width of 82 feet, Figs. 17 to 20, Plate 6; but, as the Elbe locks stand open for several hours each tide, and the Baltic locks nearly always, the length of the ships using the canal is not restricted to 490 feet. At Rendsburg, a lock, 223 feet long, 65 feet wide, and 18 feet deep, connects the canal with the Lower Eider. At this point there are two railway swing-bridges and a road swing-bridge; and two single-line railway swing-bridges cross the canal elsewhere. The swing-bridges have unequal arms, and leave a clear opening of 164 feet across the canal; and they, and also the gates, sluices, and capstans of the locks at Brunsbüttel and Holtenau, are worked by hydraulic power. The two high-level bridges at Grünenthal and Levensau have single spans of 513 feet and 536 feet respectively, and give a clear headway of 138 feet; and each carries two lines of railway and a roadway over the canal.

The canal is lighted at night, for the passage of vessels, by electric glow lamps, arc lamps being considered too dazzling. Sixteen-candle power lamps are placed 13 feet above the water-level, 73 yards apart on the sharpest curves, up to 274 yards on the straight portions. The end locks and their approaches are specially well lighted by incandescent lamps of from 25- to 60-candle power, and shaded arc lamps on the water side.

The works were commenced in 1888, and the canal opened in 1895. The cost of the works amounted to £7,800,000.

Ship-Canal between Dortmund and the Harbours on the Ems.[1]

The canal from Dortmund to the Ems is part of the proposed waterway between the Rhine, Weser, and Elbe, and connects the coalfields and manufactories of Westphalia with the port of Emden, situated at the outlet of the River Ems into the North Sea.

[1] Centralblatt der Bauverwaltung, 1893, p. 389; 1894, p. 507; 1895, pp. 230, 509, 522, and 533; and 1896, pp. 42, 278, 302, 308, 320, 332, 333, and 575.

Route of the Canal.—The canal, which is to serve barges up to 600 tons carrying capacity, commences at the important manufacturing town Dortmund, where considerable dock works have been constructed, Fig. 21, Plate 6. At Henrichenburg, 9⅓ miles from Dortmund, the level of the canal is raised 46 feet, which is surmounted by a canal-lift. From this point there is a branch to Herne, where there is an important mine. The canal continues for 42 miles at the higher level to Münster, cutting through the water-partings of the rivers Emscher, Lippe, and Stever. The Lippe and Stever are crossed by massive aqueducts, each having three equal spans of 69 feet and 41 feet respectively, approached by canal embankments, reaching a height of 49 feet. A short branch connects the docks at Münster with the canal. At 4⅓ miles to the north of this town, the fall of the canal towards the river Ems commences. The middle reach, 21 miles long, is reached by two locks, and terminates near the village of Bevergern. It crosses the Ems by a lofty aqueduct with four openings of 39 feet. From Bevergern the proposed "Mittelland" Canal is designed to branch off to the Weser and the Elbe, *viâ* Osnabrück and Hanover, Fig. 21, Plate 6. The third lock lies behind Bevergern; while the descent to the Ems is made by six locks near the village of Gleesen. To economise water, the last of these locks, which has a depth of 21 feet, is provided with a side pond on each side, the two ponds having together a capacity of two-thirds that of the lock. The canal follows the Ems for a short distance, and then enters the Ems or Haneken Canal, built in 1824, and now widened and deepened, which it follows for 11 miles. Above Meppen, the canal follows the Hase, a canalised tributary of the Ems, and then again enters the Ems, which is canalised to Papenburg, on which length there are five needle weirs. A further use of the Ems was impossible, owing to its winding course. Papenburg is the terminus for the smaller sea-going ships, but cannot be reached by the larger vessels. At Oldersum, 18¾ miles further down, the Ems increases greatly in width, and the water is at times too rough for the canal boats, so that from this point a lateral canal has been built to Emden, Fig. 21, Plate 6. Large extensions are now being made to the port at Emden. The canal, including the branch canal to Herne, has a total length of 174 miles, of which 115 miles are canal proper, 38 miles the canalised and regulated Ems, and 20 miles the open Ems.

Description of Dortmund Canal.—The canal is 98 feet wide at the water-level, 8¼ feet deep and 59 feet wide at the bottom in cutting, and 11½ feet deep and 46 feet wide at the bottom in

embankment, which alteration of cross-section effects a reduction in the quantity of material required for the banks. The slopes, from 3¼ feet under water to 3¼ feet above the water-level, where subjected to wash and the effects of frost, are 3 to 1, and below this they are 2 to 1. The relative area of the wetted cross-section of the canal to that of the ships using it, is 4 to 1. There are eighteen locks and a canal-lift near Henrichenburg; and it is necessary to provide water for the upper half of the canal to its entrance into the Ems. The pumping-station is situated where the canal crosses the Lippe, and is capable of lifting 60,480 cubic feet of water from the river into the canal. Owing to the scarcity of water, the locks, as far as the entrance to the Ems, are constructed to take only one vessel at a time, and have an available length of 220 feet, a width of 28 feet, and a depth of 10 feet over the sills. The locks on the widened Haneken Canal, and on the canalised Ems, where plenty of water is available, are 541 feet long, 33 feet wide, and 8¼ feet deep, and can take a tug and a train of canal-boats.

All streams crossing the canal are carried underneath in culverts. The canal is crossed by about one hundred and twenty bridges, nearly all of which have a single clear span of 102 feet. Near Meppen and Lingen there are two swing-bridges, as it was impossible to raise the roads for carrying them over the canal by a fixed bridge. The canal cross-section on the three aqueducts crossing the Lippe, Stever and Ems is reduced to 59 feet by 10 feet.

The upper part of the canal, from Dortmund to the Haneken Canal, 87 miles in length, is fed by pumps from the Lippe; while from Münster to Bevergern, it is fed with water from the Ems by pumps calculated to supply 31⅓ cubic feet per second. In connection with the canal-lift at Henrichenburg, there are pumps delivering 16⅔ cubic feet per second from the Dortmund-Henrichenburg portion of the canal.

This canal-lift, with a height of 46 feet, is considerably larger than those hitherto constructed at Anderton, Fontinettes, and La Louvière, lifting vessels of from 100 to 400 tons, for here vessels of 600 tons are dealt with. The lift chamber at Henrichenburg consists of a trough or box having a clear inside length of 230 feet, a breadth of 28 feet between the guides, and containing 8¼ feet depth of water; it is hung from a bridge, and rests upon five cylindrical floats 27¼ feet in diameter. The five floats are arranged in a row under the longitudinal axis of the trough, and each moves up and down in a shaft filled with water. They are

entirely immersed, and their buoyancy exactly equals the weight of the trough and its contents. Since the whole is normally in equilibrium, weight added to the trough causes it to sink, and a reduction in its weight causes it to rise. This disturbance of the balance is effected in the first place by causing the trough to rise to a little below the level of the upper reach of the canal, so that water from this reach will flow into it; and in the second case by stopping it before it reaches the lower level of the canal, so that water will flow from it into that level. This operation is regulated by two screwed shafts on either side, which are driven by an electric motor at exactly the same speed. These screw spindles pass through nuts fixed to the sides of the trough, which they serve to keep level, and, in the event of a sudden alteration in the buoyancy of the floats, would support it. The cost of the canal was £3,725,000. At Dortmund, Münster, Papenburg, Leer, and Emden, extensive dock works are being constructed, those at Dortmund costing £271,250.

The Elbe-Trave Canal.[1]

In 1391–98 a canal was made connecting the Elbe with the Baltic, the locks on which accommodated vessels up to 62 feet long, 10 feet beam and 1 foot 5 inches draught. The construction of the North Sea and Baltic Canal made the bringing of this waterway up to modern requirements of vital importance to Lübeck; and in 1873 preliminary works for the new Elbe-Trave Canal were commenced.

Description of Canal.—The canal in course of construction leaves the Elbe at Lauenburg, then follows the valley of Knikemühle-Bach, passes over the Berlin-Hamburg railway above Büchen station in the valley of the Delvenau, enters the Mölln Lake, and then follows the valley of the Stecknitz to the port of Lübeck, Fig. 22, Plate 6. The canal is 42 miles long, and its upper reach is 17 miles long; the portion descending towards the Elbe is 7 miles, and that towards the Trave, 18 miles long. The water-level of the upper reach is 24 feet above the mean water-level of the Elbe, and 40 feet above the mean water-level of the Trave. Three locks surmount the difference of level on the Elbe side, and six that on the Trave side.

The breadth of the canal is 105 feet at the water-level, and 72 feet at the bottom; and the depth of water is 6½ feet. The

[1] Centralblatt der Bauverwaltung, 1894, pp. 500 and 521.

locks are 246 feet long and 36 feet wide, and have a depth of 8½ feet over the sills, so that the canal will accommodate the largest boats plying on the Elbe, of 800 tons capacity; and a future increase in the bottom width and depth of the canal can be effected. The lock entrances will be built independently of each other; and where the foundation is suitable, the vertical sides of the lock-chambers will be formed by arches abutting on double T-bars, the feet of which will be embedded in a continuous concrete foundation. The iron standards will be anchored back, and connected with one another by a continuous walling. The lock-chambers will have no inverts; and gates turning on horizontal axes will be used instead of vertical gates. The filling and emptying of the locks will be effected, in the case of vertical gates, by means of sluiceways in the lock-heads and gates; and in the case of horizontal gates, by culverts under the floor. Nearly all the bridges crossing the canal afford a clear width underneath of 85 feet. The estimated cost of the canal is £1,137,500, a third of which will be borne by Prussia, and two-thirds by Lübeck. The work was commenced in 1895, and it is hoped that the canal will be opened in 1899.

River Oder Improvement Works.[1]

The Oder rises in Austria, 2,080 feet above the level of the Baltic; and it has a length of 587 miles to the mouth of the Swine at Swinemünde, 507 miles of which, with a fall of 672 feet, are in Germany. Its drainage area is 46,064 square miles. The importance of the Oder is due to it and its tributaries being navigable for 1,056 miles, and being connected with all the north-eastern waterways of Germany from the Elbe to Memel. The most important of these waterways are the tributaries Warthe and Netze, the Finow Canal, and the Oder-Spree Canal. The Netze is connected with the Vistula by the Bromberg Canal, so that timber from Russia and Galicia can be floated to Stettin. The Finow Canal joins the Oder to the Havel, and is the most important connection between Berlin and Stettin. It was built by Frederick the Great in 1744–46, and, with an available depth of 4·1 feet to 4·9 feet, is used by vessels of from 150 tons to 170 tons. In 1890, 15,451 vessels passed through the Eberswalde lock on this canal.

[1] Zeitschrift für Bauwesen, 1896, Nos. vii.–xii.; of Centralblatt der Bauverwaltung, 1894, Nos. i. and ii.; 1898, No. i.; Denkschrift über die Ströme Memel, Weichsel, Oder, Elbe, Weser, und Rhein, Berlin, 1888.

To secure a better connection between the middle Oder and the Upper Spree at Berlin, the Oder-Spree Canal, for vessels up to 400 tons, was built in 1887–91. The locks on this canal have an entrance width of 28¼ feet, a chamber width of 31½ feet, a depth of water over the sills of 8½ feet, and an available length of 180 feet. The canal itself, with a depth of 6½ feet, has a width of 76 feet at the water-level and 46 feet at the bottom. The canal is so constructed that it can be enlarged in the future to admit the passage of Elbe boats of 500 tons, 203 feet long, 26 feet wide, and 5¾ feet draught. Its cost was about £650,000. This canal has materially increased the traffic between Hamburg and Silesia.

Below Breslau, a low-water depth of 3¼ feet has been obtained on the Oder by regulation; and above Breslau, that river has to carry the important traffic from the Upper Silesian coalfields and manufacturing districts. An improvement in the waterway to meet the increased requirements was urgently needed; and this section of the river, especially the upper part, was improved by canalisation. From Cosel, where the goods, mainly coals, are transferred from rail to the river boats, and where there is a considerable port, down to the mouth of the Neisse, there are, on a length of 15 miles, twelve needle weirs having a total fall of 88 feet, Fig. 23, Plate 6. The fall of the weirs varies from 5¾ feet to 8½ feet. The locks are placed near the weirs, the entrance channels being separated from the current by dams. The locks have an available length of 180 feet, a width of 31½ feet, and a depth of water of 6½ feet over the sills. Near these locks, which admit boats up to 400 tons capacity, space is left for the construction, when required, of locks, 426 feet long, capable of containing a tug and two 400-ton vessels. The length of the river also has been shortened 4 miles by various cuts. Between the mouth of the Neisse and Breslau there are two weirs on the Oder, at Brieg and Ohlau, with adjacent locks, formerly only large enough for vessels of 175 tons, which have been rebuilt to admit vessels of 400 tons.

In Breslau itself, many new works were needed to deal with the traffic of the larger vessels. Immediately above Breslau, the Oder divides itself into two arms, one of which, in passing through the town, is dammed up at two places to provide power for manufactories. The fall at one weir is 3⅝ feet, and at the other 8 feet. Vessels pass these weirs through locks, one of which has an available length of 144 feet, and the other 178 feet, while both have a width of 17⅓ feet, so that these locks are too small to accommodate boats of 400 tons. Since there were various difficulties

in the way of building larger locks near these, the new waterway for large boats is carried round the town, following for a part of the way the second arm, or Old Oder. The Old Oder, at its upper junction with the main stream, is dammed up by a fixed weir, and serves only during intermediate and high-water levels. About 547 yards below this weir, the channel for large boats branches off from the navigable Oder. The upper lock is at the entrance, and passing through it the boats gain the lower harbour and the Old Oder which serves them for 1¼ miles. From this point, a canal has been cut, having a bottom width of 59 feet, near to and following the direction of the Old Oder. It is over 1¾ mile long, and serves in winter as a lying-up place for several hundred boats. A sufficient depth of water is maintained in the upper part of the Old Oder and in the canal by a needle weir, about 547 yards below the junction of the canal with the Old Oder. Near the lower end of the canal is the old lock; and 546 yards below, the canal again enters the Old Oder. The length of this channel is 4⅔ miles; and the locks have an available length of 180 feet, and a width of 31½ feet. The canal is protected from floods by embankments; and there is a flood-gate at the upper end which ordinarily stands open, but is shut during floods by a sliding door. This gate not only protects the canal from flood-waters, but also maintains the normal water-level in the canal when the weir is lowered. The lower lock is provided with flood-gates to protect the canal from the entry of flood-water. Pumps at the lower lock replenish the loss of water, and maintain the normal level in the canal when the needle weir is lowered in winter. The foregoing works were mostly opened in 1895, and those in Breslau in 1897. The cost of the works was estimated at £1,150,000.

The Regulation of the Estuary of the Vistula.[1]

The Vistula rises in the northern range of the Carpathian Hills, near the Jablunka Pass, in the principality of Teschen, at a height of 2,132 feet above the level of the Baltic. It is 700 miles long, 211 miles of which lie in Austria, 345 miles in Russia, and 144 miles in Germany. The fall of the Vistula, from its entry into Prussia to the Baltic, is about 128 feet; and the river drains an area of 76,510 square miles, 12,860 square miles of which are in Prussia.

The regulation of the German part of the Vistula was commenced in 1880; and extensive works have been undertaken in the estuary,

[1] Denkschrift über die Ströme Memel, Weichsel, Oder, Elbe, und Rhein. Berlin, 1888; Centralblatt der Bauverwaltung, 1895, pp. 133, 365, and 369.

where the conditions were very unfavourable. Near Montan Point, 28 miles from the sea, the Nogat branches off from the Vistula, and flows in a north-easterly direction, eventually emptying itself through several shallow mouths into the Frische Haff, Fig. 24, Plate 6. From this branch, the Vistula flows nearly due north for 25 miles, where it separates into the Elbing and the Dantzig Vistula. The Elbing Vistula, after flowing 16 miles in an easterly direction, empties itself by a number of shallow arms into the Frische Haff. The Dantzig Vistula flows west, and up to 1840 passed by Dantzig; but that year, during a heavy flood, it broke through the sand dunes at Neufähr, and formed a new mouth, by which its course was shortened 9 miles. The estuary of the Vistula is embanked, and the surrounding land is fruitful and thickly populated.

The flood-waters of the Vistula have a maximum discharge of 353,000 cubic feet per second, 76,800 cubic feet to 95,300 cubic feet flow down the Nogat, and the remaining 276,200 cubic feet to 257,700 cubic feet through the Elbing and Dantzig Vistula. In spring, when ice commences to come down the main stream, the Frische Haff is mostly frozen over; and if the ice in the Lower Vistula could not get away, the greater part of the ice from the undivided Vistula often passed down the Nogat. Since this ice found no passage through the frozen shallow mouths of the Nogat, it formed dams which pent up the waters of the river, causing them to overflow and break through the embankments. Thus the shallow mouths of the Nogat and the Elbing Vistula were often unable to discharge harmlessly the flood-waters accompanying the ice. Those interested in the Nogat marshes had urged that the Nogat might be closed at the upper end, and all flood-waters forced to pass down the Lower Vistula. The inhabitants of Königsberg, which lies on the Frische Haff, and is connected with the sea by the Pillau Gut, objected strongly to this; and the Government Commission reported that the maintenance of the depth of water was largely due to the discharge of the Nogat, and a shoaling up was to be feared if the scouring action of the waters from the Frische Haff were weakened by a reduction in the flow of the Nogat. Consequently, the Government determined to retain the Nogat as an arm of the Vistula, and to prevent the flooding of the lowlands by the construction of a cut to the Baltic, 4⅔ miles long, starting below the point where the Elbing Vistula branches off, which shortened the channel by 6⅕ miles. The normal breadth of this cut is 820 feet at its upper end, increasing to 1,312 feet at its mouth. The flood-water section

between the embankments has a breadth of 2,953 feet. The embankments have a top width of 33 feet, and are formed with material taken from the cut. While it was sufficient to construct a guiding cut, 164 feet wide, through the sand dunes, and leave it to be enlarged to the full section by the scour of the current, the upper part of the cut had to be excavated to the full width, and to a depth of 6½ feet below the future mean water-level, owing to the varied character of the ground, which consisted of loam, sand, and firm blue clay. The banks of the new channel, and especially the left bank, which, owing to the curvature, would be strongly attacked by ice and floods, were protected by fascines, and loose and packed stones. The excavation, which amounted to 9,417,750 cubic yards, was commenced in the summer of 1891, and completed in 3½ years. The work was done in the dry; and at times, one Dutch and six Lübeck excavators, with an average daily output of 2,620 cubic yards, were in use. The transport of the material was effected by twenty-five locomotives and twenty trains of wagons. Including the pumping plant and two steam-cranes on the banks of the Vistula, there were forty-one steam-engines on the works. In November, 1894, the works were far enough advanced, with the exception of the guiding channel through the sand-hills, to be connected with the Vistula. To secure sufficient water in the Dantzig and Elbing Vistula mouths to carry off the ice, the new cut was not opened until after the ice had come down in the spring of 1895, when the dam at the entrance of the sandy cut was broken through, so that the flood-waters following the ice passed through the new channel. The dam was broken through in the afternoon of the 31st March, 1895; and by the morning of the 1st April, the guiding channel through the sand-hills had been widened from 164 feet to 984 feet, the current having removed 2,616,000 cubic yards in sixteen hours. Subsequently the Dantzig and Elbing Vistula were closed. Considerable additional excavation, costing £700,000, and other works have become necessary, since the closure of the Dantzig Vistula, in order to maintain the traffic from the east to Dantzig. These works, which commence about the middle of the cut, on the left bank, and reach the Dantzig Vistula at Einlage, consist of an outer basin of nearly 15 acres, from which a lock opens out, having an available length of 200 feet, a width of 41 feet, and an effective depth of 6½ feet at the lowest water-level, Fig. 25, Plate 6. The lock is founded on concrete and strongly built; and the iron gates are double-skinned, with air-chambers up to the mean water-level on the lower side. The sluices are closed by doors turning on

vertical axes. A swing-bridge carries a road across the head of the lock. The lock-gates, sluices, swing-bridge, and four capstans on the lock-heads, are worked by hydraulic power under a pressure of 711 lbs. per square inch. The ship-canal connecting the lock with the Dantzig Vistula is about 1,300 feet long.

Parallel to the ship-canal, and about 330 feet higher up, is a canal constructed for the passage of floating timber, which, with an important timber trade, was necessary to avoid congesting the main canal at certain times of the year. The timber canal is about 3,280 feet long, 36 feet wide at the bottom, and has 1 to 1 slopes. The bottom is paved with granite, 1 foot thick, laid on concrete between longitudinal and transverse sheet-piling. The slopes are protected with brickwork on a concrete bed. The canal is protected from the entry of ice and flood-water from the cut, by a pair of lock-gates and a weir. The weir consists of two gates, swinging on vertical axes near the centre, Fig. 26, Plate 6, and it is placed close behind a pair of lock-gates, to equalise the water-level, so that these gates may be opened. The weir was made to turn on a vertical axis, instead of horizontally, because it was feared that, owing to the long time it would have to remain open, its chamber would otherwise become choked by the sand and mud with which the waters of the Vistula are laden. The difference of water-level, during the season for the passage of timber between the cut and the Dantzig Vistula, is never sufficient to cause too great a velocity in the canal, so that during this period the gates and weir stand open. To enable the timber canal to be used, in case of need, for the passage of vessels, and for a tug and train of barges, a second pair of iron gates was provided, 984 feet below the first pair. Sluices have been constructed through the side walls of the gates, to allow the lock-chamber, 984 feet long, to be emptied as quickly as possible. The cost of these additions, for the navigation, was £80,000.

On the left bank of the Vistula, it was necessary to set back the embankment for 6⅛ miles above the cut, as the narrowing of the river at this part was dangerous in two ways. During floods, ice was driven against the embankment and threatened to destroy it; and the decreased width pent up the water, and hindered the discharge of the ice. The cost of this work was £180,000, half of which was for land. The total cost of the works described above amounted to about £1,000,000.

The Paper is accompanied by drawings, from which Plates 5 and 6 have been prepared.

(*Paper No. 3097.*)

"The Management, Maintenance and Cost of Public County Roads in Ireland under the Irish Grand Jury System."

By Richard Barnsley Sanders, B.E., M. Inst. C.E.

The management, maintenance, and cost of public roads are matters which very materially affect the economy, convenience, and comfort of the inhabitants, and are of great importance to trade in any locality. This is especially the case in countries which, like Ireland, are deficient in railway accommodation.

The original Act which consolidated and established the present grand jury system came into force in the year 1836. Under that and subsequent Acts all public county roads, county piers and harbours, bridges, and county buildings, baronial light railways and tramways, constructed with county guarantees, were placed under the supervision or control of grand juries. The existing system, therefore, had barely completed its diamond jubilee, when its death-knell was sounded by the announcement of the proposed substitution of elected county councils for the present grand juries.

In their original composition, though they included the principal landowners and others having the largest vested interests in the country, these juries were not constituted on a basis of popular election. They, however, included a legally qualified representative for each district (barony). Since the year 1836, these bodies have been deprived of almost all powers of taxation, such powers being now delegated to the district boards called the Baronial Presentment Sessions, representing the baronies into which each county is divided; but the number or extent of the baronies are not of any fixed ratio or proportion; they vary largely, ranging in areas between 8,000 acres and 310,000 acres. These boards are composed of the magistrates of the district, together with a statutable number of the largest ratepayers of each district, whose names are drawn by ballot out of a selection of twice the statutable number placed on lists made out at each previous assizes by the grand jury.

At the Courts of Presentment Sessions (or Baronial District Boards) all applications for works and expenditure must be made. The County Surveyor examines into all the proposed works, estimates their cost, and attends the Baronial Sessions as professional adviser, stating also the nature, necessity or utility of such works, and the sums which it would be proper to grant. The Baronial Sessions then decide by a majority of votes, first, either to approve or reject, and then, if the works are approved of, the sums which they will grant. It is usual for the Boards to be guided in these matters by the advice of the County Surveyor, but sometimes other influences are at work and professional advice is disregarded. Such works as are sanctioned are then advertised for tenders and subsequently sent up to the grand jury for approval.

The supervision and control of all public roads which are under presentment for maintenance and repair are vested in the County Surveyor, and form a very important part of the duties attaching to that office. From the nature of their appointment, which is by open competition, conducted by the civil service commissioners for each vacancy, County Surveyors must not only be highly qualified engineers, but they are also free from any party influence. The regulations relating to County Surveyors' examinations are given in Appendix I. As government officials they have an important and responsible position, though they are at times liable to serve as buffers between the ratepayers and interested or unprincipled parties, who have considerable power over them, and with whom they may not infrequently come into collision. The Assistant Surveyors are appointed by the County Surveyors, so many as the grand jury may consider necessary, but before an assistant can be appointed he must have a certificate of qualification from the Board of Public Works in Ireland. In order to obtain this certificate a nomination from a County Surveyor is necessary, recommending the candidate as a fit and suitable person for the appointment, and requesting the Board to admit him for examination, and, if the result is satisfactory, a certificate of qualification is sent to the County Surveyor, who, if he does not appoint the candidate, is requested to return the certificate to the Board of Works. These examinations are chiefly in arithmetic, mensuration, calculation of quantities, chain surveying, levelling, brickwork and masonry.

Under the grand jury system all public works must be submitted for contract, and the lowest tender must be accepted, if such tender is considered *bonâ fide*, and if the sureties are sufficient.

In cases where a work is not tendered for, the grand jury are, however, empowered to entrust the same to the County Surveyor and to direct him to execute it at a cost not exceeding the amount agreed upon by the Baronial Presentment Court. Under the original Act of 1836, this latter power did not exist, and consequently, in the absence of tenders, no work could be carried out under grand juries, a fact which was the cause of great inconvenience. Thus, in King's County more than 400 miles of important roads were at one time almost impassable, as no contractors could be induced to tender for their repair and maintenance, except at fabulous prices, settled by themselves. In order to remedy this state of things, a former County Surveyor, the late Mr. John Hill, M. Inst. C.E., with the aid of the county members and others, was instrumental in obtaining the Act, 20 & 21 Vic. c. 15; under which Act grand juries were empowered, in the absence, after due advertisement, of suitable public tenders, to cause the works to be executed by the County Surveyor, the cost being, however, limited, as above mentioned, to the amount originally fixed by the Baronial Presentment Sessions. The working of this Act has been of considerable public advantage, and has resulted in great economy, though it has entailed in many cases a vast amount of extra labour upon the County Surveyors, without additional remuneration.

In cases of sudden damage to roads, bridges, &c., by floods, landslips, or otherwise, the magistrates at petty sessions in the districts affected have special power to provide sums up to £50 for repairs; and in cases where larger sums are required, the lord-lieutenant can order Special Baronial Presentment Sessions to be held for the purpose. Provision is also made for repairs in cases of emergency, where the delay of waiting for Baronial Sessions would cause great public inconvenience.

The question of the amount of money to be expended on the repairs and maintenance of any road is settled by a majority of votes at the Baronial Presentment Sessions, and the County Surveyor furnishes estimates of expense and all necessary particulars as the professional adviser. At a subsequent sessions, which must take place after the lapse of a period not exceeding 30 days, tenders are received, contracts are drawn up, with complete bonds and sureties, and these documents must then be sent up to the grand jury, who can either adopt or reject them, as they may think fit. They have no power to alter them. All contracts are made with the Crown, and are free from stamp duty.

The contracts for repair and maintenance of roads may be

entered into for periods of 7 years, but the average periods are between 3 years and 5 years. Payments on such contracts are made twice in each year, directly after the spring and summer assizes. These contracts are generally let to local farmers, or to persons engaged in business in the district. The roads are divided for contract purposes into lengths, which vary between $\frac{1}{4}$ mile and 5 or 6 miles, according to class and local circumstances, but the methods in different counties in this respect may vary.

The materials required for the repair and maintenance of the public roads are procured under the special provisions of the Act, which gives large powers to enter upon (with certain exceptions) private property for this purpose, if it is proved to the satisfaction of the magistrates that suitable materials cannot conveniently be obtained elsewhere.

The majority of the public roads in Ireland have originally been badly constructed, and this is especially the case with those roads, hill-cuttings, retaining-walls, &c., carried out by the government as relief works during the famine years 1846–8. The works of a similar kind carried out under the supervision of the County Surveyors under the Relief of Distress Act, 1880, are in striking contrast to the earlier undertakings, and the expenditure in proportion to the amount of work done was very much less. An outline of the method of road construction adopted by the Author may be given. For a main road, running through sound upland districts, as soon as the work of making the open side drains, cuttings, embankments, bridges, culverts, fences, &c., and the formation level is well consolidated, it is thoroughly drained by mitre and covered longitudinal side drains, made with stones, and discharging by small cross drains or pipes under the sides, footpaths, and fences, into the open back drains. Stone pitching, of size and depth calculated according to the traffic the road is intended to carry, is laid carefully on the formation level, closely packed, levelled, and formed to a convex cross section, and joined into the tops of the longitudinal (covered) side drains. For roads carrying very heavy traffic, and town streets, the pitching generally consists of stones about 9 inches in depth, well rammed. In country districts, the pitching consists of one or two layers of 6-inch to 4-inch and 3-inch to $2\frac{1}{2}$-inch stones. When the pitching or foundation has been well rammed and levelled, the "macadam" metal, broken to 2-inch gauge, is spread in layers not more than 3 inches deep at a time, and blinded over with fine screening, gravel, or other suitable materials, and the road is opened for light traffic; the succeeding layers of metal are applied

in a similar manner until the proper depth is obtained, which varies between 6 inches and 9 inches, according to the class of road or street. The surface is finished with a transverse fall from the centre to the sides of 1 inch in 4 feet. In towns and villages the side channels are paved with good pebble paving, and in country districts the side channels, or "water tables," are formed in the surface, by the junction of the same with the edge or curb of the footpath, or side margins; and the surface water is discharged through small outlets 9 inches by 6 inches, built under the footpaths and fences, into the open back drains.

In making roads across peat bogs, their nature and depth is first carefully ascertained. If the bog is sound, and resting on a clay or firm bottom, the road can be made without brushwood or timber.

The side-drains are first cut for such a depth into the solid sound peat as will not lower the water more than about 18 inches or 2 feet below the surface of the intended road. Outside parallel drains are then cut, at distances and depths calculated according to the nature of the bog, and the depth to which it may eventually be cut out for fuel. The side drains are connected with the outside parallel drains by small cross drains. The whole is then allowed to stand for a few months, to drain and settle down. When so drained and consolidated, and the water has assumed its altered level in this part, the space to be occupied by the roadway is then cleared, by removing all the top and light portions of bog, down to the sound solid peat; on this is laid a layer of good tough grass sods with grass side down, and over these is laid clay, or good stiff soil, in thin layers carefully punned for a depth of from 6 inches to 9 inches; over this (if obtainable) is spread a layer of fine gravel or coarse sand, and then the broken metal is laid on, as described for upland roads. The Author does not use stone pitching or heavy stones for a solid foundation in making bog roads.

If a floating or "shaking" bog has to be crossed, the side and parallel drains are made as described, but each as shallow as possible so as to avoid weakening the mass of floating peat crust. After the drains are cut on such bogs, the site usually sinks very much, and must stand until it attains somewhat of a permanent level. The top is then cleared over the site for the roadway, and a bed of gorse, heather, or very fine bushes, is carefully laid down on the wet peat, and layers of fascines or strong brushwood well crossed are laid over it, of size and depth according to the weight of the traffic to be carried. All the brushwood, &c., is filled

in with moist peat, the whole being brought up in this way to the proper level, on which grass sods are laid, and the roadway is constructed as already described for firm bogs. It is essential that all the brushwood, &c., should be laid below the line of saturation at such a level as will ensure its being kept constantly wet, together with the peat packing; as peat being a powerful antiseptic, all, if kept in a wet state, is preserved from decay.

When the Irish roads came under the control and supervision of trained and experienced civil engineers as County Surveyors, they were found to be in a very bad state, and the country was too poor to warrant the expenditure needed to remake them. Consequently all that these officers could do was to try and improve the roads as far as possible with the means at their disposal, and this has been no easy task under the existing conditions, which are briefly as follows:—

(1) The grand jury are bound to put up all work to tender, and to accept the lowest tender, even if the amount named is obviously inadequate, provided the tenders be considered *bonâ fide* and the sureties sufficient.

(2) The contracts are usually let to men who are ignorant of and unskilled in the performance of the work that they undertake.

(3) The sums allowed by Presentment Sessions are often quite insufficient, while in other cases, if a "job" has to be perpetrated, more money than is needed is allowed by the Sessions.

These are some of the difficulties with which the County Surveyors have to contend, and they are only able to overcome them by the exercise of constant care and vigilance, and by fearless discharge of their duties.

In 1836 there were 13,191 miles of roads under repair and maintenance by the grand juries in Ireland, the annual cost being £228,316, or an average cost of £17 6*s.* per mile. In 1895 there were 53,064 miles of roads under them, at an annual cost of £660,532, or an average cost of only £12 9*s.* per mile. Had the average expense remained unchanged, the total expenditure would now be £918,007, or £257,475 in excess of the present outlay. This fact is all the more remarkable when it is remembered that the usual pay of a labourer in 1836 was but 6*d.* per day, while the present rate of pay averages from 1*s.* 6*d.* to 2*s.* 6*d.* per day. Moreover, since 1836, all the main and post roads have been placed under the grand juries. These latter roads were previously maintained by the Board of Public Works and by the various turnpike trusts. In the face, therefore, of an increase of between three- and fourfold in the price of labour, and with the addition of

all the roads that are most expensive to maintain, there has actually been a saving to the country of no less than £257,475 per annum.

The total cost of supervision by County Surveyors, together with their assistants and staffs, is at the rate of about 4¼ per cent. on the expenditure. The tax for the repair and maintenance of the public roads amounts to an average rate of about 1*s.* in the £1 on the valuation.

The highest prices paid for the repair and maintenance of county roads are found in the immediate vicinity of the cities of Dublin and Belfast, where steam-rollers are employed, and there the cost reaches £394 to £470 per mile; while in the wholly rural districts the prices fall to £2 per mile, and even less.

The principal materials available for repairing and maintaining roads over the greater part of Ireland, are the different kinds of limestone, which vary considerably in character and in hardness, from the light friable and indurated chalk to the hardest blue limestone. In some districts trap, basalt, granite, syenite, whinstone and clay-slate are, however, in use. In all parts of the country it is necessary to employ the nearest available materials, as means of transit are wanting to bring stone from a distance. Limestone, though good enough for roads of light traffic, is, as is well known, not well adapted for roads carrying heavy traffic.

The system pursued by the Author in effecting the improvement of roads, has been, first, to pick out any large stones making their appearance at the surface, and to replace them with broken metal; second, to increase the thickness of the crust of the roads, and to bring them to a better formation; and third, to improve the drainage as far as possible. In the case of old roads which have never been properly constructed in the first instance, this course was the only suitable method, since many such roads were originally simply lanes, pass-ways, or private roads. These were subsequently presented for "repairs" merely by the grand jury, though they should really in many cases have been presented "to re-make," as they have since become important thoroughfares. It is often surprising to find how much has been accomplished by the above-mentioned methods in bringing these imperfect roads into fairly good condition at a nominal cost, but such roads are not of course adapted for continuous heavy traffic.

The Author has in his charge about 1,000 miles of public roads under maintenance and repair, and the only local stone available is blue or grey limestone, either in the rock or in drifts of gravel and boulders. In certain of the mountain districts it is possible to make use of the local clay-slate or sandstone grit, but these

materials are of inferior quality, and they can only be employed for mountain-roads, where the traffic is very light.

A large number of Irish roads traverse great stretches of peat-bogs or floating morasses, some of which are of considerable depth, and the Author has found that in the maintenance of these roads the management of the longitudinal side-drains is of the greatest possible importance. If the subsoil is drained too much, the peat, when it becomes dry, loses all its glutinous matter, rots away and crumbles under the crust of the road, and the road then becomes liable to drop into holes. He has found that the soundest bog-roads are those in which the level of the water in the longitudinal side-drains is kept at about 18 inches below the surface of the road. This can best be managed by forming small, shallow side-drains with cross drains to discharge the flood-water into larger parallel drains, cut into the bog at a considerable distance away from the road, and made deeper than the adjacent side-drains. Under such circumstances the peat beneath the road always retains sufficient moisture to keep it in a sound condition, and it does not part with its adhesive qualities; while in the case of roads crossing peat-bogs, which have been cut out for a considerable depth below the level of the road, and too close thereto, the roads are always in an unsound condition, and they appear to expand or contract according to the state of the weather. The crust of the road is then broken up, and is caused to ravel in very dry weather, though it heals up again and remains firm when the weather is wet. The Author has further observed that roads over peat-bogs are not so much injured by frosts as are the upland roads.

The system of repair generally adopted in Ireland is that of "darning" or patching, and the Author's specifications (Appendix II) provide that the parts to be repaired are to be picked and loosened to a depth of ½ inch (rather more at the edges), the new materials are then to be spread over the same, and are to be blinded over and consolidated with a pounder. In very wet weather, and after frost, on roads of heavy traffic, the picking and pounding are omitted, as the stones bind at once; but if the roads are repaired during spring, summer or autumn, picking and pounding are required. On the roads in the Author's charge, the metal for light traffic districts is broken between 1 inch and 1½ inch in size, and for roads of heavy traffic to about 2-inch gauge. Gravel is also extensively used for light traffic roads and for summer repairs, in those districts in which it is procurable.

It is advisable to apply the patches of new metal alternately

at each side of the road, extending therefrom to a little beyond the centre, and at distances of from 25 yards to 30 yards apart. A clear footway is thus obtained for horses to travel on without treading on the fresh patches which the wheels roll in, and ease and comfort is experienced in driving when only one wheel crosses a patch at one time. If the roads are systematically repaired in this way, taking up alternate portions and not applying too much material at any one operation, they may be brought into very good condition without the aid of rolling. It is well to provide for a stipulated annual minimum supply of materials, calculated according to the requirements of each road, so far as the same can be ascertained. These supplies should be delivered by measurement on or before the 25th September in each year, and should be worked into the roads on or before the 1st April following, with the exception of a small stock of finer materials for summer repairs.

Steam-rolling has not been adopted to any extent in Ireland, except in the outskirts of the large towns; and the powers under the Grand Jury Acts are insufficient to admit of the purchase or use of such rollers by County Surveyors.

The footpaths along certain of the public roads are principally made with a surface of gravel or fine screenings from the road metal. In a few cases near towns, concrete, asphalt and tar-paving have been used for this purpose; but the employment of concrete *in situ* has not been recommended where gas- and water-pipes exist, owing to the difficulties of opening, closing, and repairing it. The repair and maintenance of ordinary footpaths are generally included with the cost of the adjoining roads, and the figures already quoted comprise the outlay upon the footpaths.

The system of letting contracts for repairs to the local farmers, though it is attended with some advantages, is fraught with drawbacks. As the contractors, with the aid of their sons and friends, themselves execute the work, it is difficult to ensure regular and systematic attention to it; and the plan is open to considerable jobbery and to certain dishonest practices, which can only be kept in check by the utmost vigilance on the part of County Surveyors and their assistants.

If honest local contractors could be secured who would undertake contracts for roads over a considerable extent of country, the system might answer well, but it is impossible, in most places, to find substantial men willing to accept such work. Moreover, skilled workmen are really needed for the repair and maintenance of roads, but they cannot be procured except by training, and most

people at present consider that no skill or training is necessary for this class of work. The Author has adopted a system of giving short lectures, illustrated by chalk sketches, to the road contractors for each district, and he has also supplied printed directions in the specifications for the execution of the work; also instructions as to procuring materials (Appendix III) and other important details. By such means as these, accompanied by frequent inspections and by stoppage of payments for imperfect work, he has succeeded, in all cases in which he has been well supported locally, in obtaining excellent work. If the County Surveyor has to execute the work with labour and materials procured by him, he is not free from difficulties, often caused by interested and unscrupulous opposition. In King's County wherever the Author has been able to group the roads under his charge into sections of 8 miles to 12 miles (within reasonable walking distance for the men) he has appointed gangers and staffs of trained men on each section; and in this way he has formed districts consisting of about 35 miles to 50 miles, over which he has placed overseers to supervise the work, take the time from the gangers, make out the pay-sheets, and generally carry out his instructions. Where the amount of money placed at his disposal was often very much less than contractors' prices, it has thus been possible to keep the roads in excellent order and to pay the increased staff, cost of implements and all expense of works, out of the money saved under this system; but the plan has met with considerable opposition from parties whose interests were certainly not identical with those of the ratepayers.

Stone-breaking machinery is not in general use, and the Author has found that where materials can be procured conveniently near the roads for which they are required, it is at present cheaper and better to rely upon hand-breaking. The hand-broken stones are sounder and more cubical than the machine-broken stones, and they wear longer as road-metal. Owing to the relative cheapness of labour in Ireland, handbreaking is much less expensive than in England, the prices ranging from 1*s.* 6*d.* to 2*s.* per cubic yard. In King's County the present average rate is about 1*s.* 6½*d.* per cubic yard, and expert breakers earn between 20*s.* and 30*s.* per week in summer, paid by the job.

The main roads in Ireland are not generally so good as roads of the same class in England and Wales, but the average maintenance cost of the Irish main roads (if small steam-rolled portions in the neighbourhood of Dublin and Belfast are omitted) may be taken at about £42 per mile. Considering the difference in cost, and

bearing in mind the fact that the nearest available materials have in all cases to be used in Ireland, these main roads compare very favourably with those of England and Wales, while the secondary roads in Ireland are vastly superior to those of the same class in the latter countries. It may be stated generally that the cost of £12 9*s.* per mile for maintenance and repairs has produced (under the supervision of the County Surveyors) a network of roads in Ireland which must be considered remarkably good; and it will be interesting to see what effect the new system, about to be introduced, of Local Government by popular election, will have upon the public roads in respect of cost and the condition in which they will be maintained.

It is to be hoped that under the new *régime* some better system will be devised than that which prevails in England with reference to divided authority between County Councils and District, Parish, and Urban Councils in the matter of costs and responsibility. The adjustment of these matters has given rise to much friction, and the existing Irish system is by no means exempt from similar difficulties. Grand juries, it will be remembered, have at present only the necessary powers to "repair" and "maintain" or to "make new roads," constructed with stone or gravel, while the Town Improvement Acts give to Town Commissioners the requisite powers for flagging, paving, &c. The Public Health Acts confer upon Sanitary Authorities the necessary powers to scavenge, cleanse, drain and sewer the towns. Latterly, especially in the South of Ireland, the practice has been for Town Commissioners and Sanitary Authorities to endeavour to transfer their duties and responsibilities to the Grand Juries, and to throw upon these bodies the cost of works which they have no statutory powers to undertake. It is true that such cases generally arise at the District or Presentment Sessions, but it will be necessary under a new scheme of Local Government to define clearly the relative duties of each authority and to provide for their proper execution; otherwise it is to be feared that the evils of the present system will tend to be greatly aggravated.

APPENDIXES.

APPENDIX I.

Regulations relating to County Surveyors' Examinations.

The subjects for County Surveyors' examinations are grouped into two parts, viz., Part I, Theoretical, and Part II, Practical. The subjects comprised in Part I are Mathematics, including Geometry, Trigonometry, Algebra, Differential and Integral Calculus, and Geometrical Optics; Mechanical Philosophy, including Statics and Dynamics, Hydrostatics and Hydraulics, Pneumatics and Heat regarded as a source of power; Experimental Science, including Inorganic Chemistry, Heat, Electricity and Magnetism, Geology and Mineralogy. Part II comprises Railway and Canal Engineering; Marine Engineering, including Harbours, Docks, and Reclamation Works; Hydraulic Engineering, including Water-supply, Sewage and Irrigation; County Works, including Architecture, Roads, Drainage, and River works. Each of the subjects in Part II includes the drawing of designs, estimates and specifications, and mechanical contrivances connected therewith, for works required as described in the examination papers. The successful candidates must, after the examination, shew that they have been engaged in the actual practice of their profession for an adequate time on important works, either of their own design, or as responsible engineers in carrying out such works.

APPENDIX II.

General Specification Form for Maintenance of Public Road in King's Co.

1. Immediately after the presentment is made at the ensuing Assizes, the surface is to be cleaned, holes and ruts levelled, stagnant water drained off, dangerous holes fenced, the road made safe and convenient for traffic, and afterwards repaired as hereinafter specified, from time to time, or continuously as may be necessary, and maintained constantly in good order during the contract, clean, hard, and even at all seasons, and without having at any time a large quantity of fresh material on the surface.

2. The working or gravelled way is to be at least feet broad, defined by parallel lines, straight or regularly curved according to the direction; in towns or villages the gravelled way is to extend to the paved channels or edges of the footpaths, and to the fences or buildings where there are no footpaths.

3. The surface of the working way is to be formed with a slight curve transversely, having a fall from the centre to the side of 1 inch to 4 feet.

4. An offset is to be made each side of the working way, of sods or clay, at least 18 inches wide and 4 inches above the level of the water tables, neatly trimmed to the lines above specified; the offsets and the wastes at each side of the fences are to be kept clear from loose stones, rubbish and weeds, levelled evenly and preserved in grass.

5. The surface is to be kept clean and made even, by picking and levelling

ruts and inequalities, by picking up and removing all stones appearing that are above 2 inches in their greatest dimensions, and by a judicious application of new materials when necessary.

6. There are to be applied annually cubic yards of broken stones and cubic yards of prepared gravel, and more if necessary for the proper maintenance of the road.

The broken stones to be sound and hard, each particle to be not more than 2 inches in its greatest dimensions, free from clay, sand, or any extraneous matter.

The gravel to be prepared free from clay, sand, or small particles less than ½ inch in their least dimensions, and free from stones above 1½ inch in their greatest dimensions.

The materials are to be delivered for measurement on or before the 1st October each year, in depots arranged, and distributed at suitable intervals on the sides or margins of the road, but not out on the working way, squared, and put up 1 foot deep and so as to contain 10 cubic yards each. The sites for the depots must be levelled and cleared off, and the bottom made perfectly even. The materials when squared and ready for measurement are to be 1 foot in depth, and if found on opening any depot that it is made up on banks, clay, uneven surfaces, or otherwise in such manner as might deceive the Assistant, the same will be considered as fraudulently made up and proceedings may be taken accordingly. The Assistant will not be bound to measure more than two depots—any two he may select. Materials which are of an unsuitable quality or not properly prepared as specified will not be measured, and the contractor will get no credit for such materials. The stones and gravel to be in distinct heaps, distributed as may be directed. Notice in writing of the delivery of the materials is to be served on the Assistant before the 25th September, in each year.

The materials are to be judiciously applied to the worn portions of the surface, to correct the formation and increase the strength of the crust, in pieces not less than 1 yard nor more than 5 yards in length, in the form of the worn portions, not squared and in no case in drills, but disposed skilfully to induce the traffic to beat promiscuously over the working way. At each application the old surface is to be picked and loosened to the depth of ½ inch—rather deeper at the edges, and large stones to be picked out; the pieces are to be kept raked in and consolidated by blinding and pounding. When the surface becomes rutted, which can only occur by bad management or neglect, the drills are to be picked transversely and levelled, to let the water drain from the ruts to the sides, and pieces put in as before directed; the whole supply of materials specified are to be applied from time to time during the winter and spring seasons, before the 1st April each year; but on roads of very heavy traffic a small portion (if directed by the Surveyor) may be reserved for repairs in wet weather that may occur in summer and autumn.

7. The water tables are to be kept clean, and sufficient outlets made and kept open for the proper discharge of the surface waters, the gullets clear, back, side and catch drains, with outfalls, to be scoured and deepened, if necessary, for the effective drainage of the road; the waters adjoining to be kept at least feet below the surface.

8. The stuff scraped from the surface is to be removed as soon as practicable from the working way, and used together with stuff taken from the water tables, drains, or in any way procured, in the operations herein specified for levelling and raising the sides, repairing fences, or otherwise for the benefit of the road, as directed by the Surveyor, and the remainder removed.

9. The pavements and parapets of the bridges and gullets on the road are to be repaired when necessary, and all works connected therewith preserved from damage, trespass, and free from dung heaps and nuisances; notice of any sudden damage by flood or otherwise, to be given to the Surveyor in writing within two days of the occurrence.

10. The contractor is to provide, at his own expense, all implements and materials necessary for the execution of the works, and a copy of this specification, and produce it to the Surveyor when required.

11. The whole of the works herein specified are to be executed in a judicious, effective, and workmanlike manner, in every particular necessary for the repair, constant maintenance in good order, and improvement of the road, according to the true intent and meaning of this specification, and to the satisfaction of the County Surveyor.

12. The footpaths along the road to be maintained in good order, by picking up and removing the large stones, correcting the formation, and by the application of properly prepared materials.

All fences erected at the expense of the county to be kept in repair by the contractor.

APPENDIX III.

Instructions as to Materials.

The materials must be prepared of the size specified, and are to be delivered for measurement on or before the 1st October next, in depots arranged, and distributed at suitable intervals on the sides or margins of the road, but not out on the working way, squared, and put up not less than 1 foot deep, and so as to contain 10 cubic yards each. The sites for the depots must be levelled and cleared off, and the bottom made perfectly even. The materials when squared and ready for measurement are to be 1 foot in depth, and if found on opening any depot, that it is made up on banks, clay, uneven surfaces, or otherwise in such manner as might deceive the Assistant, the same will be considered as fraudulently made up, and proceedings may be taken accordingly. The Assistant will not be bound to measure more than two depots—any two he may select. Materials which are of an unsuitable quality, or not properly prepared as specified, will not be measured, and the contractor will get no credit for such materials. The stones and gravel to be in distinct heaps, distributed as may be directed. Notice in writing of the delivery of the materials is to be served on the Assistant before the 25th September next.

The total quantity which you are bound to have supplied on or before the 1st October is   cubic yards of broken stones, and   cubic yards of prepared gravel, but if the full quantity is not out, properly distributed, and ready for measurement on the 1st October, the application for payment will be disallowed at Sessions.

Contractors will not be permitted to deviate from the specification by substituting gravel for broken stones, or broken stones for gravel, unless permission in writing is given to the contractor.

(*Paper No. 3120.*)

"Karachi Sewerage Works."

By James Strachan, C.I.E., M. Inst. C.E.

Since the completion of the Karachi Water Works[1] in 1883 and the introduction into the city of a copious supply of sweet water, the necessity for a system of sewerage, especially for the native town, has been daily a matter of increasing importance. The consumption of water had in 1893 reached 1½ million gallons per day, while the quantity of sullage and waste water daily removed from the city did not much exceed 5,000 gallons. The improvement in the health of the people due to the introduction of pure drinking-water has therefore been, as was anticipated, followed by periods of increased sickness, caused, no doubt, by the absence of proper means for the removal of waste water, sullage, night-soil, &c. The Municipal Commissioners were fully alive to the needs of the city in this respect; but, as in the case of the Water Works, they found that the great obstacle in the way of carrying out a comprehensive scheme was the want of funds. Between the years 1886 and 1890 several schemes were prepared by the Author, and discussed by the corporation, for sewering the whole city, including the military cantonments adjoining; but they were abandoned chiefly on the score of expense. Eventually it was decided to raise a loan amounting to 6 lakhs of rupees (£40,000), and with that amount, as the matter was pressing, to take in hand first that part of the city known as the Old Town Quarter.

From time immemorial, the sullage and other waste waters of the Old Town Quarter have been either collected in cesspools, of which there were a great number, or thrown on the surface of the streets and lanes, with the usual result that the soil was soaked with sewage, and the health of the inhabitants was thereby endangered. Previously to 1875, these cesspools were built according to the will and pleasure, or, more probably, according to the means at the disposal of the persons constructing them.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 333.

Generally they were simply holes dug in the ground some 10 feet or 12 feet deep, without lining of any kind, so that their contents could all the more easily percolate through, or be absorbed by the surrounding ground. They were never cleaned, for their contents escaped readily enough into the gravelly soil, and the pipes connecting them with the houses were never trapped.

Since 1875 an improved style of cesspool has been insisted on by the authorities, with walls properly lined, and with the connecting pipe properly trapped; moreover, all cesspools are periodically cleaned and are properly ventilated, but, notwithstanding this, the need for a proper system of sewerage still remained.

The rainfall of Karachi, though as a rule very limited, is occasionally extremely heavy, amounting at times to nearly 1 inch in an hour, and the area drained by the present storm-water channels is very large, amounting to about 3,000 acres. The discharge therefore is, in time of rain, very great; and to provide for such a very heavy rainfall in the new drains would be almost an impossibility. It was therefore resolved to exclude the storm-water from the sewers.

In discussing the question as to the proper means of disposing of the sewage, it was admitted that the tidal outfall system had much to recommend it, especially to the inhabitants of a sea-board town like Karachi, and it appeared to be at the first glance the system most suitable for the city; but the only convenient place for the discharge of the outfall sewer was into the harbour, immediately to windward of the town. This in itself would have been an insuperable objection, even if the other objection raised by the Harbour Board to sewage being discharged into the harbour could have been overcome. The idea of disposing of the sewage by discharging it into the sea was therefore abandoned. The system of disposing of the sewage by applying it to land was then considered. The main objections to this method of disposal in England are easily overcome in Karachi. On the north of the Lyari River there was a sufficient area of land, Fig. 1, Plate 7, under the control of the Municipality, admirably situated for a sewage farm; and as the rainfall of Karachi is, as a rule, so limited, the crops which might be produced on the farm would not be subjected to any ruinous competition by crops irrigated in the ordinary manner. It was decided, therefore, that the sewage should be utilized on the land.

The part of the city which the corporation decided to sewer first is bounded by the Lyari River on the north and west, by Napier Road on the east, and by Bunder Road on the south,

Fig. 2, Plate 7. It is raised but a few feet above high-water mark, and it was owing to this fact that the Author recommended to the corporation the adoption of the sectional system of sewers, coupled with the Shone hydro-pneumatic ejectors. The area to be dealt with measures about 175 acres, and the population within it is estimated at 30,000.

This drainage area is, for the purposes of the scheme, divided into five blocks, each containing a population of about 6,000. The estimated quantity of sewage from each block was 15 gallons per head per day, or a total from five blocks of 450,000 gallons. To deal with this quantity of sewage, two Shone ejectors were erected at convenient points in each block. They are each of 200 gallons capacity, and arrangements were made so that their contents could be automatically discharged by compressed air once a minute.

The advantages of dividing a town built on flat ground into separate sewerage districts; the possibility of using pipes of small diameters and laying them with steep gradients; the reduction of water for flushing purposes; the avoidance of large sewers and deep cuttings; and the ease with which the Shone system can be extended as new areas are populated are now fairly well recognised. The ejectors are connected by cast-iron air-pipes with the air-compressing engines, and from each ejector a cast-iron discharge-pipe carrying the sewage, runs from the ejector to the sewage farm. The sewers in each block gravitate to the main manhole near the ejector station, and a cast-iron pipe connects the main manhole with each ejector station. The machinery for compressing the air comprises two steam-engines of the horizontal compound non-condensing type, each with two steam-cylinders (one high- and one low-pressure) and two air-cylinders. The diameter of the high-pressure cylinders is 10 inches, and that of the low-pressure cylinders 16 inches, while the air-cylinders have each a diameter of 11 inches, all having a stroke of 18 inches. Each engine is of about 25 nominal HP., and is capable of compressing sufficient air to deliver 375 gallons of sewage per minute from the five ejector stations to the outfall against a maximum dynamic head of 131 feet of water, of which 72 feet are due to pipe friction.

Expansion-valves are fitted to both high and low-pressure steam-cylinders. When exhausting from the high-pressure cylinder, the steam enters a receiver before passing into the low-pressure cylinder. All steam-cylinders and valve-chests are lagged with wood. The air-cylinders are cooled by water-jackets, the water for this purpose being pumped from a well outside the boiler-house.

The two boilers are of the dry back multitubular type; each is capable of supplying sufficient steam at 120 lbs. pressure per square inch to work one of the air-compressing engines.

For economy, as at present the engines are not working to their full power, the boiler fire-grate area has been reduced from 13·6 square feet to 9 square feet, the remaining portion having been bricked up. Wrought-iron retarders have for the same reason been fitted to the tubes with very good results, the temperature of the products of combustion passing through the smoke-box to the chimney having thereby been reduced from 420° F. to 200° F.

The air-mains, tested to 60 lbs. to a square inch, which convey the air under pressure from the receiver near the compressing engines to the ejectors, are of ordinary cast-iron piping, 3 inches to 5 inches in diameter, laid with lead joints. From the ejectors to the outfall the discharge sewage main consists of cast-iron pipes with turned and bored joints. The pipes vary between 7 inches and 12 inches in diameter.

The works connected with the ejector stations entailed excavating a well at each station 16 feet square, within which the tubbing (which forms the outer walls of the ejector station) had to be fixed. The tubbing is composed of cast-iron flanged plates $\frac{7}{8}$ inch thick with $1\frac{1}{4}$ inch flanges built up in sections. Access from the road to the ejectors (which are erected inside the tubbing) is obtained by means of a manhole and a cast-iron circular shaft in which a wrought-iron ladder has been fixed. The joints of the tubbing-plates were all carefully planed and fitted together before being finally erected, and, to ensure their being perfectly watertight, lengths of flattened lead piping were placed in them; the plates were then screwed together, and the joints were finally caulked.

The gravitation sewers in which the sewage flows to the ejectors consist in each district of ordinary cast-iron or earthenware pipes, according to the nature of the excavation. The pipes vary in diameter between 5 inches and 9 inches, and were laid with gradients varying between 1 in 80 and 1 in 150, so as to make them thoroughly self-cleansing.

The five manholes near the ejectors were built of cut stone, and were put together in two concentric rings, with a fillet of pure Portland cement 1 inch thick between them. The joints were made to break bond both vertically and horizontally. The other manholes were constructed with rubble masonry or with Portland-cement concrete.

Each main gravitation sewer is provided at its summit level with an automatic flush-tank, of a capacity varying with the length

of the sewer, and supplied with water by a pipe from the nearest water-main. Disk flush-tanks are provided at the summit level of all the shorter lines of sewers. These tanks are periodically filled with water from carts kept for the purpose, and it is found sufficient if these smaller sewers are flushed every third day. The automatic flush-tanks are arranged to discharge their contents once in 48 hours. The gravitating sewers are ventilated according to the Shone-Ault system, which consists of an inlet air-shaft of cast-iron between 7 feet and 12 feet high, fixed at the upper end of each sewer, and communicating with the sewer by means of a pipe carried from the bottom of the shaft to the manhole at the head of the sewer. An outlet ventilating-shaft of cast-iron, of a height sufficient to carry the discharged air above the neighbouring houses, is erected on a suitable site near the ejector.

Between the ejector-chamber and another chamber built at the foot of the outlet ventilating-shaft, is laid an exhaust-pipe fitted to a nozzle in the latter chamber. When the compressed air has forced out the sewage, the exhaust-pipe is automatically opened, and the air passes rapidly along it, causing an intense current down the inlet shafts at the heads of the sewers. The main manhole into which all the gravitating sewers discharge, is connected with the nozzle chamber by a pipe, and thus all foul air escapes by the outlet shaft. The system of ventilation adopted has proved very efficient, no difficulty having ever been experienced by any of the men who attend to the manholes in entering them at any time, nor has any trace of foul air ever been noticed. No blocks have occurred in the main sewers, and only a few in the branch sewers, caused chiefly by sticks and stones being maliciously pushed into the sewers through either the gully traps or the manholes. The following are the gradients given to the gravitating sewers :—

5-inch sewers	1 in 80
6 „ „	1 in 100
7 „ „	1 in 125
8 „ „	1 in 150
9 „ „	1 in 200

Immediately after the opening of the works, a sixth ejector was laid down to deal with a large quantity of waste water from the bathing ghats of the Hindoos. It is worked by compressed air conveyed by a branch pipe taken off the air-main leading to No. 5 ejector, and its discharge-main joins the original main from No. 5 ejector. In connection with this ejector, a large

night-soil depôt has been erected, provided with wrought-iron receptacles into which the contents of night-soil carts are tipped and then flushed into the sewer. The water used for flushing purposes is drawn from a well within the enclosure by a small horizontal direct and double-acting pump, which is actuated by compressed air from the air-mains.

The following Table shows details of the scheme:—

No. of Ejector Station.	Discharge per Minute.	Diameter of Main Discharge Pipe.	Length of Main Discharge Pipe.	Inlet Level of Gravitating Sewers.	Discharge Level of Ejector.	Ground Level of Ejector Station.	Lift to Outfall.	Length of Gravitating Sewers.	No. of Automatic Flush Tanks.	No. of Disk Flush Tanks.	Population.
	Galls.	Ins.	Yards.				Ft. Ins.	Yards.			
1	29	7	277	44·01	40·51	57·38	56 6	4,321	10	34	5,012
2	46	7	66	44·47	40·97	57·09	55 0	3,873	10	30	5,389
		8	540								
3	72	7	31	44·81	41·31	58·36	54 8	4,756	11	41	7,326
		9	618								
4	96	7	163	47·47	43·97	60·60	52 0	4,825	12	29	7,562
		10	483								
5	68	7	659	46·25	42·75	61·68	53 3	2,358	6	28	5,394
		12	3,463								
6	32½	6	325	43·00	36·83	57·47	59 2	1,659	2	6	1,500

House-connections were at first not very numerous, owing to the habits of the people and to their objection to the outlay involved in making them, but it is anticipated that connections with the drains will soon be general within the sewered area. At present some five hundred house-connections have been made, and several hundred applications for them remain undisposed of. The majority of the house-connections are for sullage and waste water only; 4-inch earthenware pipes are carried from the gravitating sewer to a siphon-trap, which is placed on the house-drain close to the outer wall. Between the siphon-trap and the wall of the house a 4-inch ventilating pipe is erected and carried up a few feet above the roof of the house. Sink stones and night-soil depôts have been provided along the lines of all the gravitating sewers, to enable scavengers to discharge into them sullage water and excremental wastes, which are thence flushed into the sewers.

The sewage is discharged at the farm, at a level of 59·70 feet above the level of the discharge-pipe of the lowest ejector, into a tank of 15,000 gallons capacity, provided with an automatic siphon, so that its contents could be discharged on the farm in a

few minutes. It was found, however, that the discharge from the full tank was greater than the men in charge of its distribution could conveniently cope with, and accordingly arrangements have been made whereby the sewage is discharged on the farm at the same velocity as it flows from the main.

The land reserved for the sewage farm measures about 800 acres, but the area at present laid out is 60 acres. The farm is intersected by masonry channels or carriers for a certain portion of its area, and for the rest the carriers are of earth. The site of the farm slopes from the foot of the Mangah Pir hills to the Lyari River, and is fully exposed to the strong breezes which blow from the sea from April to October. These breezes have a most damaging effect on all plant life; efforts have therefore been made to afford to the crops as much shelter as possible by dividing the farm into 4-acre blocks and running round each block cart roads, along the sides of which trees have been thickly planted. The soil of the farm varies between light sandy loam and hard black caking earth several feet thick; the subsoil is all gravel. Water is not to be found nearer the surface than 18 feet. Various plans for irrigating the fields were tried and were abandoned as unsuitable. That now followed gives satisfaction from a sanitary point of view, inasmuch as the sewage is not only quickly disposed of, but the land is irrigated without any offensive smell. Each field measures 1 acre, and for irrigation it is divided into beds 20 feet wide and the full length of the field (198 feet).

The sewage, which is brought to the upper end of the ground in earthen channels, is run on to a bed till it has reached about three-quarters of its length; it is then turned on to another bed, and the same process is repeated until the whole field has been irrigated. The fields have a fall of 4½ inches per 100 feet; and the sewage, which is cut off when it has reached three-quarters of the length of the field, is sufficient to irrigate the whole bed before it ceases flowing. There is no effluent from any field. The whole of the liquid part of the sewage is either evaporated by the sun or is absorbed by the soil within a few hours after it is run on to a field. A watering once in 8 days or 9 days is sufficient for all the crops yet tried on the farm.

The following are the crops already tried:—

Guinea-grass	*Panicum Jumentorum.*
Lucerne	*Medicago Sativa.*
Chubber	*Cynodon Dactylon.*
Italian rye-grass	*Lolium Italicum.*
Sugar-cane	*Saccharum Officinarum.*

These crops may be called perennials, as, with the exception of sugar-cane, they will, under favourable circumstances, continue growing for several years without being renewed or re-sown. All have grown well and have given heavy yields.

Juar	*Sorghum Vulgare.*
Bajri	*Panicum Spicatum.*
Makai, or Indian corn	*Zea Mays.*
Wheat spelt	*Triticum Speltix.*
Common barley	*Hordeum Vulgare.*
Millet	*Panicum Miliaceum.*

With the exception of barley, which tillered too much, and the stalks of which were too weak to support their own weight, all the above crops did well. Indian and European vegetables also proved successful. The guinea-grass forms a good crop for a sewage farm; 2 acres were planted during April 1895, and the yield to end of March 1896 was 196,507 lbs. of green fodder. In the climate of Karachi lucerne yields all the year round, but its period of most luxuriant growth is the cold season, from the beginning of November to the end of March. A plot measuring 1 acre gave four cuttings between those dates, the combined weight being 30,385 lbs. The quantity of seed used was 30 lbs. to the acre. Chubber, unlike lucerne, is of slow growth during the cold season; 2 acres under this crop yielded in all 33,189 lbs. between the dates mentioned. Italian rye grass sown in the cold season yielded in the first cutting 13,475 lbs. from 2 acres. Of sugar-cane the yield was 4,383 canes from $\frac{1}{3}$ acre, from the beginning of November to the end of March. This was not considered a satisfactory crop. Juar grew well till it was attacked by caterpillars, from the effects of which it suffered greatly. Bajri is not a favourite fodder, yet cattle seem to thrive very well upon it; it is not subject to the attacks of moth larvæ. A crop occupied the ground 51 days, and yielded 27,450 lbs. from 1 acre. Of green fodder, makai or Indian corn has a ready market in Karachi. It is a very suitable sewage farm crop, occupying the ground for only $2\frac{1}{2}$ months. It yields between 16,000 lbs. and 24,000 lbs. per acre of green fodder. Unfortunately it is very subject to the attacks of moth caterpillars. Wheat spelt or wheat barley proved more satisfactory than ordinary barley. An acre sown on the 15th December, 1895, was ready for cutting as green fodder on the 15th February, 1896. The harvest continued until the 1st March, 1896, and the quantity realized was 25,240 lbs. Common barley is not considered a suitable crop for a sewage farm. Common millet was little known in the

neighbourhood until it was tried on the sewage farm in Karachi. An acre sown on the 7th December, 1895, was fit for cutting on the 11th February, 1896, or a little over 2 months from the date of sowing. The harvesting continued as the grass was required up to the 3rd March, and the total quantity harvested was 25,887 lbs. to the acre. This crop can be grown in Karachi all the year round, but is best suited for the cold season.

The following is a statement of the number of gallons of sewage delivered on the farm by the ejectors during 12 months ending June, 1896, and for the 6 months ending the 31st December, 1896:—

—	Gallons delivered.	Cost.	Cost per 1,000 Gallons.	
		Rs.	Annas.	Pies.
From 1st July, 1895, to 30th June, 1896	60,360,000	10,308	2	8·75
From 30th June to 31st December, 1896	42,518,257	7,543	2	10·0

The expenditure in connection with the working of air-compressors and ejectors for 12 months from 30th June, 1895, to 30th June, 1896, a period in the aggregate of 3,018·25 hours, was as follows:—

			Rs.
Coal, 267 tons at 22 Rs. per ton			5,874
Oil, sundries, and contingencies			250
Engineer in charge, Rs. 125 per month			1,500
Engineman,	Rs. 45 „	„	540
Stoker,	Rs. 20 „	„	240
Cleaner,	Rs. 13 „	„	156
Boy boiler-cleaner,	Rs. 7 „	„	84
Ejector inspector,	Rs. 20 „	„	240
Sub-inspector,	Rs. 14 „	„	168
„ „	Rs. 14 „	„	168
Mehtar (ejector),	Rs. 12 „	„	144
„ „	Rs. 12 „	„	144
Flush inspector,	Rs. 15 „	„	180
Cart driver (Mehtar),	Rs. 10 „	„	120
Maintenance charges			500
	Total annual charges		Rs. 10,308

To test the efficiency of the whole system, the Author resolved that careful trials should be made, and that the results should be recorded for future reference.

Cardiff steam coal of fair quality was used, but it had been standing in an open-air stack for 10 months. It was carefully weighed, and at the close of the trial the amount of clinker and incombustible ash were deducted from the total quantity used. The trial showed a consumption of 3·8 lbs. of coal per I.HP. per hour, the pressure above the atmosphere being kept during the trial at 110 lbs. per square inch. Diagrams were taken from both the steam- and the air-cylinders. The trial showed that the air-cylinders developed 29·23 I.HP., and the steam-cylinders 35·69 I.HP., so that the engine efficiency, which was taken as the ratio between the two, was 0·819. On stopping the engines at noon, all outlets from the air-mains at the ejectors were closed, and it was found that the pressure of air at that time indicated 30 lbs. per square inch on the gauge in the engine-room. At the end of the 2 hours' stoppage, the gauge indicated a pressure of 25 lbs. per square inch, or a fall of $2\frac{1}{2}$ lbs. per hour. On starting the engines again at 2 o'clock, it was found that 150 revolutions were required to raise the air-pressure in the mains to the normal working pressure, viz., 30 lbs. per square inch. As during the engine trial it was ascertained that the engine made 80 revolutions per minute, or 4,800 revolutions per hour, and as the loss by leakage for 2 hours was equivalent to 150 revolutions of the engine, the total percentage of constant leakage at all times would be $\frac{75}{4800} = 0\cdot0156$ of the whole. This would give the efficiency of the air-mains $1\cdot0000 - 0\cdot0156 = 0\cdot9844$.

The total quantity of sewage lifted during the trial was 531 gallons per minute, the dynamic head, as shown by the air-pressure in the mains, was 69·2 feet; the ejectors therefore developed

$$\frac{531 \times 69\cdot2 \times 10}{33{,}000} = 11\cdot135 \text{ horse-power.}$$

The efficiency of the ejectors is found by dividing this horse-power by that in the steam-cylinders taken from the diagrams, thus $\frac{11\cdot136}{35\cdot689} = 0\cdot312$.

From these results the combined efficiency of the system was found to be as follows:—

1.	Efficiency of engines	0·819
2.	„ „ air-mains	0·9844
3.	„ „ the compressed air as a working fluid	0·458

$$0\cdot819 \times 0\cdot9844 \times 0\cdot458 = 0\cdot369,$$

which is the theoretical coefficient of efficiency of the machinery. When there is sufficient work to keep the engines working constantly at full power, the efficiency of the system will doubtless improve.

The following statement shows in detail the cost of the entire scheme:—

Description of Works.	Total Expenditure. R.	A.	P.
1. Purchase of pipes: cast-iron pipes, 29,777 lineal feet; earthenware pipes, 31,202 lineal feet	50,375	15	3
2. Excavating trenches, laying and jointing pipes, excavating and building manholes, &c.	101,375	10	5
3. Excavating and building five manholes	2,214	10	2
4. Excavating and building flushing siphons, and erecting ventilating pipes	30,172	3	10
5. Excavating and erecting night-soil depôts . . .	945	4	2
6. Building engine and boiler-house, engineer's bungalow, and works at farm-yard	34,103	5	3
7. Supplying, erecting, and fitting engines and boilers; supplying and erecting ejectors; supplying and laying sewage and air-mains	355,758	1	6
8. Establishment and contingencies	22,054	13	5
Grand total . . . Rs.	597,000	0	0

The Paper is accompanied by seven tracings, from which Plate 7 has been prepared.

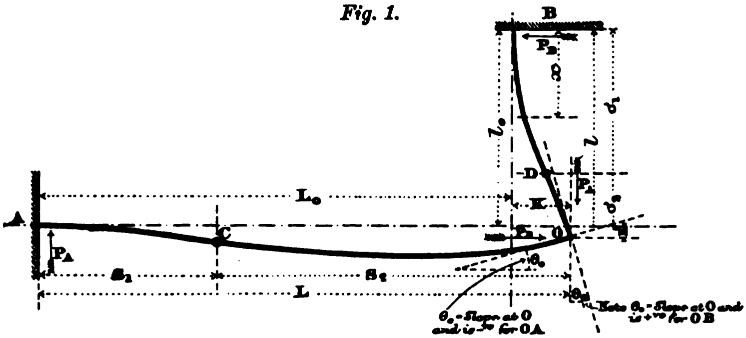
(Paper No. 3085.)

"Stresses in Pipes bent at Right Angles caused by heating to the Temperature of Steam at various Pressures."

By THORNYCROFT DONALDSON, M.A., Assoc. M. Inst. C.E.

NOTWITHSTANDING the recent great increase of boiler pressures, especially in marine engineering practice, data does not appear to be available to show whether the stresses in a steam-pipe, caused by expansion due to increase of temperature, are sufficiently

Fig. 1.



reduced by arranging a bend in the pipe. In the hope of contributing towards a fuller knowledge of this matter, the Author presents the following investigation, with an account of certain experiments bearing upon it.

Fig. 1 represents a pipe bent at right angles, of which the two arms, originally straight and bolted firmly by flanges to a rigid framework, have become deflected by increase of temperature. In the following investigation the "strut effect" of the reaction due to the short arm is regarded as having no effect upon the curvature and deflections of the long arm; that is, the long arm is considered to be affected only by a couple at its end and a force perpendicular to it, and not by a force parallel to it; and so for the short arm. It will be shown later that this assumption is approximately justified, except where the ratio of the long to the short arm is very large.

The nomenclature used is obvious from the *Fig.*, observing that $\frac{L}{l} = \rho$. Consider first the short arm O B; at any point distant x from B, the bending moment $M = P_B(\sigma_1 - x)$; and at O, where x becomes equal to l, $M = P_B(\sigma_1 - l)$. The curvature y'', at a point distant x from B, is $\frac{M}{EI} = \frac{P_B(\sigma_1 - x)}{EI}$; and at point O, where $x = l$, $\frac{M}{EI} = \frac{P_B(\sigma_1 - l)}{EI}$. Hence it follows that the slope at O, $y' = \frac{P_B(\sigma_1 - \frac{1}{2}l)\,l}{EI}$, and the deflection at O,

$$y = \frac{P_B}{EI}(\tfrac{1}{2}\sigma_1 - \tfrac{1}{6}l)\,l^2.$$

The value, y, is equal approximately to the expansion of O A, and may be written $y = a\,L$; where a is the coefficient of expansion for the range of temperature considered. Dealing similarly with the long arm O A, the curvature at O, $y'' = \frac{P_A}{EI}(s_1 - L)$; the slope at O, $y' = \frac{P_A}{EI}(s_1 - \frac{1}{2}L)\,L$; and the deflection at O,

$$y = \frac{P_A}{EI}(\tfrac{1}{2}s_1 - \tfrac{1}{6}L)\,L^2 = a\,l.$$

Since there is equilibrium and continuity at O, it follows that (1) the bending moments, and therefore the curvatures, in the two arms, are equal at O; (2) the slopes in the two arms are equal at O, but of opposite sign.

Hence the following equations may be formed:—

$$\frac{P_B}{EI}(\tfrac{1}{2}\sigma_1 - \tfrac{1}{6}l)\,l^2 = a\,L \quad . \quad . \quad . \quad . \quad (1)$$

$$\frac{P_A}{EI}(\tfrac{1}{2}s_1 - \tfrac{1}{6}L)\,L^2 = a\,l \quad . \quad . \quad . \quad . \quad (2)$$

$$\frac{P_A}{EI}(s_1 - L) = \frac{P_B}{EI}(\sigma_1 - l) \quad . \quad . \quad . \quad (3)$$

(that is, the curvatures are equal at the point O.)

$$\frac{P_A}{EI}(s_1 - \tfrac{1}{2}L)\,L = -\frac{P_B}{EI}(\sigma_1 - \tfrac{1}{2}l)\,l \quad . \quad . \quad (4)$$

(that is, the slopes are equal but of opposite sign at the point O.)

There are th[illegible] equations between the four unknown quan-

tities P_A, P_B, s_1 and σ_1. Solving for s_1 and σ_1, to derive the points of inflection—

$$\frac{s_1 a - b}{s_1 c - d} = \frac{s_1 \alpha - \beta}{s_1 \gamma - \delta} \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

and hence
$$s_1 = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \quad . \quad . \quad . \quad . \quad (6)$$

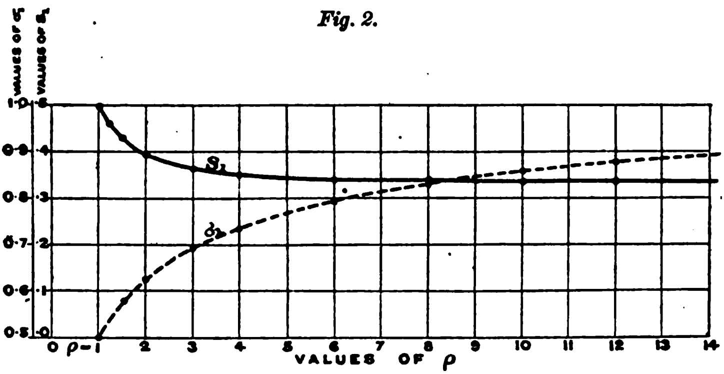
where
$$a = \tfrac{1}{2}\rho^2 + \tfrac{1}{3}; \qquad \alpha = \tfrac{1}{2} + \rho;$$
$$b = \frac{L}{6}(1 + \rho^2); \qquad \beta = \tfrac{1}{2} L(\rho + 1);$$
$$c = 1 + \rho^2; \qquad \gamma = \rho + 1;$$
$$d = L\left(\tfrac{1}{2} + \frac{\rho^2}{3}\right); \qquad \delta = L(1 + \tfrac{1}{2}\rho);$$

and
$$A = a\gamma - \alpha c;$$
$$B = \beta c - b\gamma + \alpha d - a\delta;$$
$$C = b\delta - \beta d.$$

Also
$$\sigma_1 = \frac{s_1 \alpha - \beta}{s_1 \gamma - \delta} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Hence s_1 may be evaluated in terms of L for various values of ρ. Also noting that when $\rho < 1$, s_1 becomes σ_1, σ_1 may be expressed in terms of l, though it is simpler to evaluate σ_1 from equation (7) and from the values of s_1 which have already been found. These values are given by the curves in *Fig. 2*, the dotted curve being for s_1 and the full curve for σ_1.

Fig. 2.



Writing $\sigma_1 = \sigma l$, where σ is the fraction given by the curve, equation (1) gives

$$P_B = \frac{2 E I \alpha L}{(\sigma - \frac{1}{3}) l^3};$$

But at B, where the bending moment, and therefore the stress, is greatest,

$$M = P_B\,\sigma_1 = P_B\,\sigma\,l$$
$$= \frac{2\,E\,I\,a\,L\,\sigma}{(\sigma - \frac{1}{3})\,l^2};$$

therefore the maximum stress at B

$$= f = \frac{M}{z} = \frac{M}{\frac{I}{y}} = \frac{M\,D}{2\,I}$$
$$= \frac{2\,E\,I\,a\,L\,\sigma\,D}{(\sigma - \frac{1}{3})\,l^2 \cdot 2\,I} = \frac{E\,a\,L\,\sigma\,D}{(\sigma - \frac{1}{3})\,l^2}$$
$$= \frac{E\,a\,\rho\,\sigma\,D}{(\sigma - \frac{1}{3})\,l}$$
$$= \frac{E\,a\,\sigma\,\rho\,\lambda}{\sigma - \frac{1}{3}} \quad \ldots\ldots\ldots \quad (8)$$

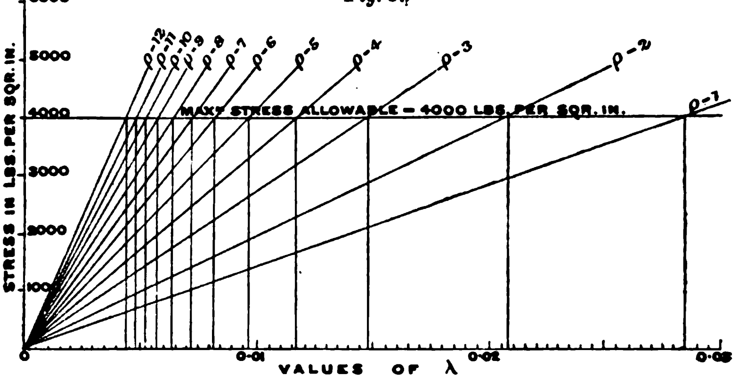
where D is the external diameter of the pipe and $\frac{D}{l} = \lambda$.

Now suppose ρ is constant, and, therefore also σ, then

$$f = a\,\lambda,$$

and this equation, a being a constant, represents a series of straight lines giving the maximum stress at B for different values of λ,

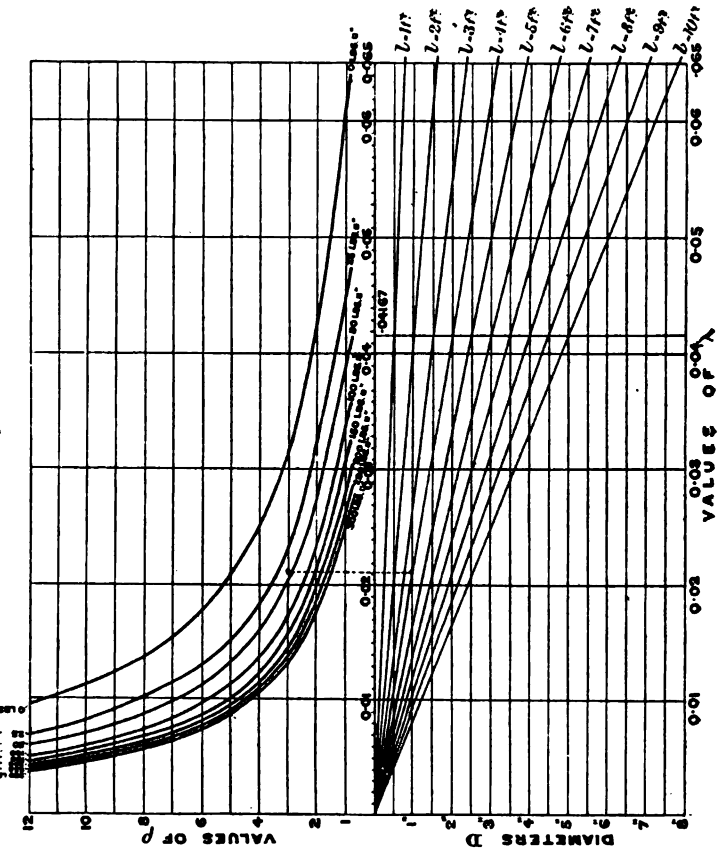
Fig. 3.



along each of which ρ is constant. Such a series is given in *Fig. 3*, in which E has been taken as 15,000,000 and a the temperature range in degrees F. multiplied by $0 \cdot 00000955$, the pipe being assumed to be of copper. A horizontal line on this diagram through the maximum permissible stress (taken in this case to be 4,000 lbs.

per square inch) gives the maximum permissible value of λ for each value of ρ; and these are plotted in a series of curves in *Fig. 4*, where each curve corresponds to a given range of temperature. If for any given pipe, the values of ρ and λ be the co-ordinates of a point on the convex side of any curve in the *Fig.*, then the pipe is stressed beyond the maximum permissible limit

Fig. 4.



by heating through the range of temperature belonging to that curve. For plotting the curves in *Fig. 4* the values of λ are calculated from equation (8), which may be written

$$\lambda = \frac{f}{\dfrac{E\,a\,\sigma\,\rho}{(\sigma - \frac{1}{3})}}.$$

The same values of E, a, and f, are used in *Fig. 4* as in *Fig. 3*. The lower part of the diagram gives the values of λ for various values of D and l.

As regards the "strut effect" referred to, it is evident that the maximum bending moment due to it occurs at the point of maximum deflection, and is equal to half that deflection multiplied by P_B, which acts at the point of inflection C, assuming O A to be undeflected by the force P_B.

Now, by equation (1),

$$P_B = \frac{a\,L\,E\,I}{l^2\left(\frac{1}{2}\sigma_1 - \frac{1}{6}l\right)} = \frac{a\,\rho\,E\,I}{l^2\left(\frac{\sigma}{2} - \frac{1}{6}\right)}.$$

The maximum deflection takes place where the slope is zero, so that

$$s_1 = \tfrac{1}{2}x,$$

or

$$x = 2\,s_1 = 2\,s\,L,$$

and its value is

$$= \frac{P_A}{E\,I}\left(\tfrac{1}{2}s_1 \times 4\,s_1^2 - \tfrac{1}{6}\,8\,s_1^3\right)$$

$$= \frac{2\,P_A\,s^3\,L^3}{3\,E\,I}.$$

The maximum bending moment produced by P_B is therefore

$$= \frac{P_A\,s^3\,L^3}{3\,E\,I} \cdot \frac{a\,\rho\,E\,I}{l^2\left(\frac{\sigma}{2} - \frac{1}{6}\right)}$$

$$= \frac{P_A\,s^3\,L^3\,a\,\rho}{3\,l^2\left(\frac{\sigma}{2} - \frac{1}{6}\right)} = \frac{P_A\,s^3\,\rho^3\,a\,L}{3\left(\frac{\sigma}{2} - \frac{1}{6}\right)}.$$

Again, the maximum bending moment in the long arm due to P_A occurs at O, and is equal to

$$P_A\,(s_1 - L) = -\,P_A\,(1 - s)\,L.$$

Comparing these two bending moments and neglecting the sign, since magnitudes only are being considered, it is seen that their ratio R

$$= \frac{a\,s^3\,\rho^3\,L\,P_A}{\frac{3}{2}\left(\sigma - \frac{1}{3}\right)(1 - s)\,P_A\,L} = \frac{a\,s^3\,\rho^3}{\frac{3}{2}\left(\sigma - \frac{1}{3}\right)(1 - s)}.$$

Giving a the value corresponding to 300 lbs. per square inch and evaluating, it appears that

when ρ is 12, $R = \frac{1}{2 \cdot 5}$;

when ρ is 10, $R = \frac{1}{4 \cdot 15}$;

when ρ is 6, $R = \frac{1}{16 \cdot 2}$;

and when ρ is 3, $R = \frac{1}{82 \cdot 4}$.

Now the effect of this bending moment is to increase the deflection of the long arm and so relieve the stress in the short arm. It has been shown that it is only of sensible magnitude, compared to the bending moment caused by P_A, when ρ is very large (say 10 and upwards), and, consequently, σ is large (say 85 per cent. and upwards); hence any lengthening of σ_1 will be small, and will not much affect the stress B. Moreover, the curves are always on the right side. The strut effect in the short arm is obviously so slight that it need not be considered.

Consider, lastly, the compression in the long arm due to the direct thrust P_B. It may conveniently be compared with the expansion which will produce the maximum permissible stress at B. Now the stress at B

$$= \frac{M}{Z} = \frac{M\,y}{I} = \frac{P_B\,\sigma_1\,y}{I} = f,$$

and $$P_B = \frac{f\,I}{\sigma_1\,y};$$

Δ being the sectional area of the copper in the pipe. The total compression $= \frac{P_B\,L}{\Delta\,E}$

$$= \frac{f\,I\,L}{\Delta\,\sigma_1\,y\,E} = \frac{\pi f L\,(D^4 - d^4)}{\frac{\pi}{4} E\,\sigma_1 \times 32\,D\,(D^2 - d^2)}$$

$$= \frac{f\,L\,(D^2 + d^2)}{8\,E\,\sigma_1\,D} = \frac{f\,\rho\,(D^2 + d^2)}{\sigma}.$$

If the pipe be large and thin, this approaches $\frac{f\,\rho\,D^2}{4\,E\,\sigma\,D}$, or $\frac{f\,\rho\,D}{4\,E\,\sigma}$, as the maximum compression for any given values of D, ρ and f.

Now the expansion due to increased temperature being a L, the ratio of these expressions is

$$= \frac{f \rho \mathrm{D}}{4 \mathrm{E} \sigma a \mathrm{L}}$$

$$= \frac{f \mathrm{D}}{4 \mathrm{E} a \sigma l} = \frac{f \lambda}{4 \mathrm{E} a \sigma}.$$

But the largest value of λ on the *Fig.* is about 0·06, and the minimum value of σ is 0·5; hence the largest value to be considered is

$$\frac{4{,}000 \times 0 \cdot 06}{0 \cdot 5 \times 4 \times 16 \cdot 5 \times 10^6 \times 0 \cdot 00334}$$

$= \frac{1}{460}$ which may be neglected. The effect of this again is to decrease the stress at B.

The compression in the short arm is clearly much smaller, and although the thrust producing it tends slightly to increase the stress on the compression side at B, it may be neglected.

The comparisons instituted may appear to form a crude method of investigating these disturbing effects; but the full treatment in the original equations would be complicated, as the solution of the simultaneous equations of the second degree (1) to (4) is already somewhat troublesome.

It may here be noted that should the pipe be permanently deflected it will at the next equal expansion be stressed to the point at which it is about to take a further permanent set. If the pipe be given a deflection when fitted, the range of stress will be the same as the maximum stress would otherwise have been. Also, as a rule, a pipe is not warmed more than once a day, so that in 10 years it only receives about 3,650 loadings or repetitions of stress, and it may therefore be very near the elastic limit without danger, if submitted to no vibration.

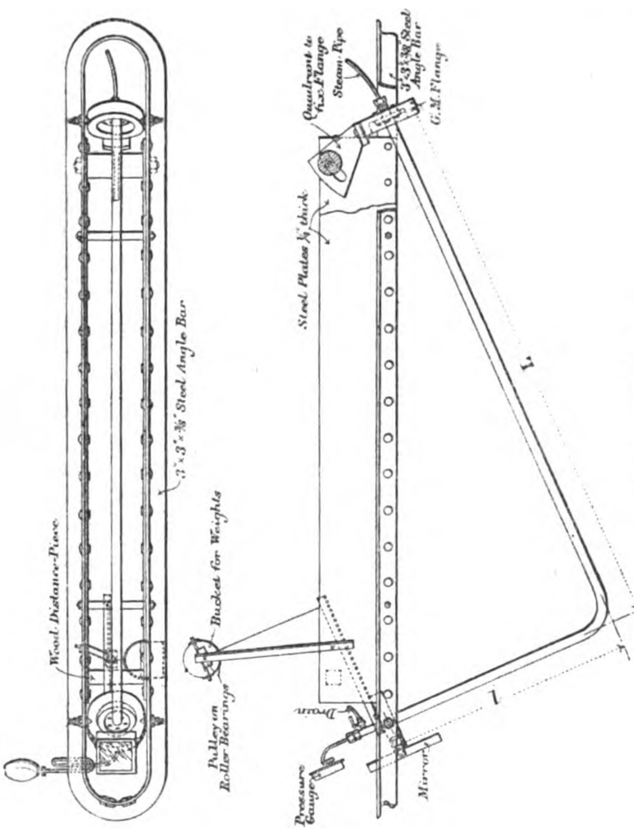
Experiments.

Several experiments were made, by deflecting pipes on a surface-table, which tended to show that the elastic modulus of the pipes was about 16½ millions; and though the elastic limit was much reduced by annealing, it did not appear that the modulus was much affected.

Experiments were also made by the deflection method at different temperatures to discover any change in the modulus of elasticity at the temperatures of steam at one or two pressures; but the best of these experiments, that is to say, those in which

the best precautions were taken to drain the pipe and so prevent deflection from unequal expansion, seemed to show that the difference is inappreciable at temperatures due to steam-pressures up to 150 lbs. per square inch. The experiments were of the workshop rather than of the laboratory order; but still the deflection method admits of considerable accuracy, the principal difficulty (apart from that of the draining mentioned) being to obtain the correct

Figs. 5.



Scale, ¼ inch = 1 foot.

APPARATUS TO ASCERTAIN THE STRESS IN COPPER PIPES DUE TO EXPANSION.

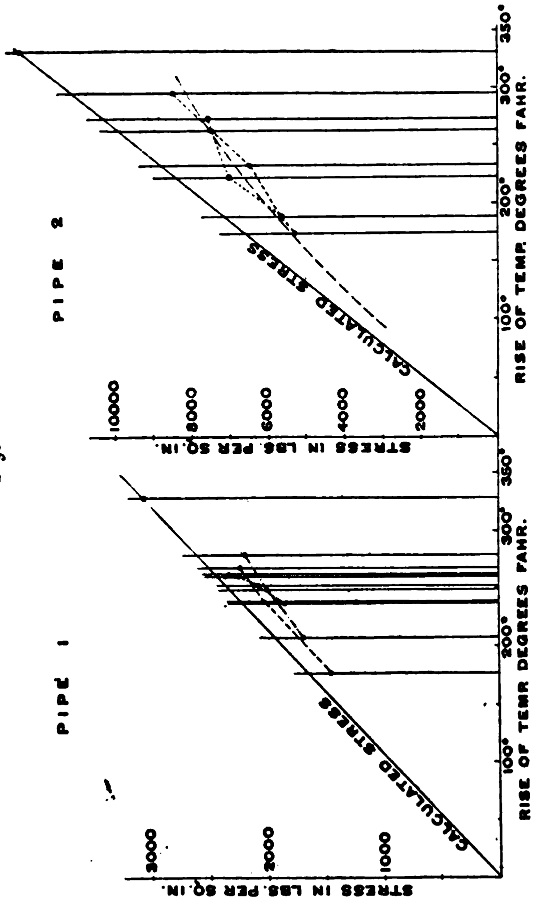
modulus of the section, as solid-drawn pipes are rarely of the same section throughout.

Another experiment was made to obtain the linear expansion due to increase of temperature of a copper pipe. This appears to decrease slightly at higher temperatures and to amount to a total of 0·00275 for 300° rise from 60° F., or 0·0000092 per degree F. The figure, however, adopted in all these calculations is 0·00000955

per degree or 0·00286 for 300°, as being that given by good observers between 32° and 212°.

Finally, to test the validity of the formula given by equation (8) for f, the stress at B, a stiff frame was made with two stout flanges pivoted on centres, as shown in *Figs. 5.* To one of these flanges was attached a quadrant by which it could be readily

Figs. 6



COMPARISON BETWEEN ACTUAL STRESSES AND THOSE FOUND BY EXPERIMENT.

clamped in any position, and to the other was fastened a small angle-bar, from the end of which a cord was led horizontally to a pulley fitted with roller bearings. This pulley was carried on an adjustable arm, and by hanging a weight on the end of the cord a turning moment was produced in the flange which could be accurately measured. A large mirror was also attached, with a

mark and distant slit, in a movable piece of cardboard, to indicate the rotation of the flange. The idea of using this slit, instead of a beam of light in the usual manner, was not due to the Author. Between these two pivoted flanges, a pipe, bent at right angles and provided with ordinary jointing flanges, was fitted, and securely bolted to them, care being taken in bolting up that there should be no initial stress produced in the pipe. To the centre of the flange A, with the clampable bracket, was attached a long flexible steam-pipe, and to the other, B, a flexible drain-pipe and a pressure-gauge. The flange A having been clamped, and the position of the flange B noted by means of the mirror and slit apparatus, the steam was turned on and the pipe expanded, turning the flange B, which was next brought back to its original position by hanging weights on the cord. The pipe was thus in the same condition as if bolted to a rigid framework and expanded; while the temperature was obtained by means of the pressure-gauge, and the stress was calculated from the length of the arm and the weight on the cord which produced the turning moment necessary to bring the flange B back to its original position.

Figs. 6 show the stresses calculated by equation (8) for the two pipes experimented upon, compared with the actual stresses observed, due to the turning moment produced in the flange B by the weights applied to the cord at the different temperatures. These observed stresses are fairly consistent, and agree as nearly as may be expected with the theoretical values, considering the uncertainty in the values of E and of a, as well as the disturbances due to the "strut effect" and to the compression already discussed. At the higher temperatures pipe 2 was stressed beyond the elastic limit. Hence the falling off in the curve.

It is worthy of note that where pipes are subjected to considerable vibration, in addition to stresses caused by expansion, they quickly give way at the flanges where there is local softening and weakness, even with the most careful manufacture—a point which is of growing importance in these days of high speeds.

The Paper is accompanied by six tracings from which the Figures in the text have been prepared.

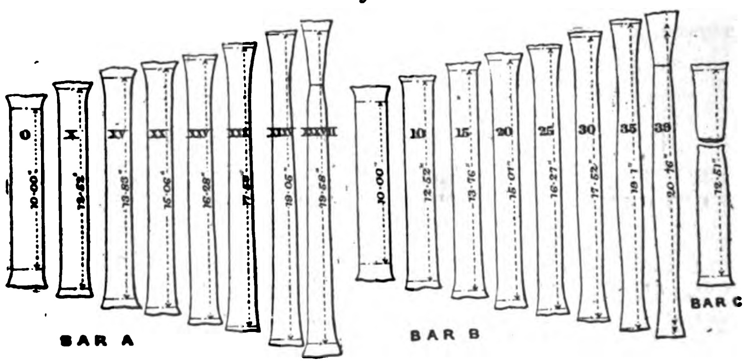
(Paper No. 3098.)

"Note on the Endurance of Steel Bars subjected to repetitions of Tensional Stress."

By Ernest George Coker, B.A., B.Sc.

This Paper relates to a series of experiments upon two mild stee bars, which were repeatedly subjected to tensile stress carried beyond the breaking-down point, the amount of extension being kept approximately the same throughout the experiments. The chief points it was desired to determine were:—(1) The total amount of extension to be obtained under such conditions; (2) whether the tensile stress at breaking-down point was influenced by successive stretchings and annealings; and (3) the ratio of the work done on a bar

Figs. 1.



Scale, 1 inch = 1 foot.

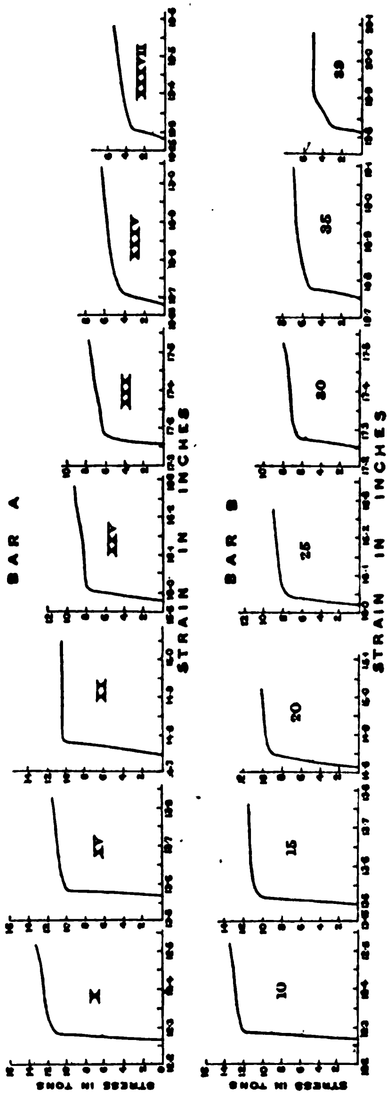
broken under ordinary conditions to that done on a similar bar broken under the conditions given.

Three bars of mild steel were cut from the same piece of boiler-plate, and were annealed and machined to size by a special machine in the testing-house. They were 10 inches long, 2 inches broad, and 0·44 inch thick. A chemical analysis showed that the amount of combined carbon in the steel from which the test-pieces were made was 0·16 per cent. Two of the bars, marked A and B

respectively, were subjected to tensional stress followed by annealing, and the third bar C was broken in the ordinary manner.

The testing-machine first used was of the Wicksteed type, with a beam to test up to 50 tons, the jockey weight being 1 ton. The testing-machine afterwards used was capable of exerting a pull of 100 tons, and was similar to the smaller one except in details, the most important being that the beam was short and the jockey weight was 2 tons. The extensions of the bars were measured by a Kennedy extensometer of the ordinary type, to measure to 0·001 inch, and, for the rougher measurements, a pair of beam compasses with fine points was used, which, with the aid of a magnifying glass, gave measurements accurate to 0·01 inch.

Figs. 2.



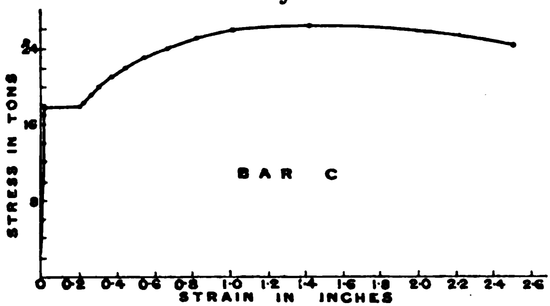
It was found by experiment upon other similar bars that when the breaking - down point was reached, the sudden extension at this point was rather less than 0·25 inch, and it was decided to extend each bar 0·25 inch before annealing and commencing anew. Occasionally an extension of 0·3 inch was reached before the load could be taken off. At the conclusion of each experiment the bar was measured and afterwards annealed by an experienced tool-smith. The annealing was per-

formed by heating the entire test-piece to a dull red heat in an ordinary blacksmith's fire, and allowing it to cool in lime. The percentage of combined carbon being small, there was little danger of burning the plate during heating.

The dimensions of the bars at the conclusion of the tenth, fifteenth, twentieth, twenty-fifth, thirtieth, thirty-fifth and last experiments are shown in *Figs. 1*, together with the corresponding stress-strain diagrams, *Figs. 2*. The figures marked with Roman numerals refer to bar A, and those with ordinary figures refer to bar B.

Extensions of the Bars.—The total extensions of the bars A and B, treated in the manner described, are approximately four times that of the bar C broken in the ordinary manner, *Fig. 3*. The bar A was subjected to thirty-seven extensions before it broke, involving as many annealings; and its length when fractured

Fig. 3.



measured 19·58 inches between the measuring points. The bar B was subjected to thirty-nine extensions before it broke, and its length when fractured was 20·76 inches. The ratio of the extensions of the bars A and B to that of the bar C are as follows:—

$$\frac{\text{Extension of bar A}}{\text{Extension of bar C}} = \frac{9 \cdot 58}{2 \cdot 57} = 3 \cdot 73$$

$$\frac{\text{Extension of bar B}}{\text{Extension of bar C}} = \frac{10 \cdot 76}{2 \cdot 57} = 4 \cdot 18.$$

These results do not differ more than might be expected, having regard to the possible sources of error, such as extending the bar beyond the fixed amount (0·25 inch), uneven setting in the testing-machine, etc.

Breaking-Down Point.—The second point which it was sought to determine [illegible] the stress per square inch at or near the breaking-[illegible]ed with the number of annealings to

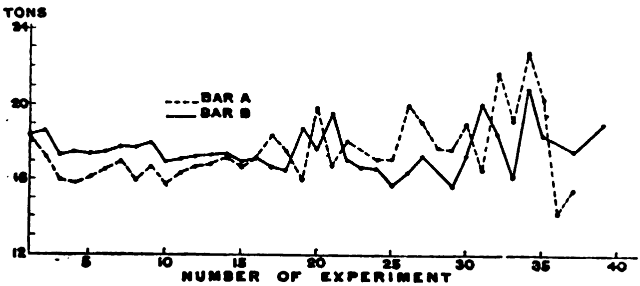
which the bar was subjected. It was assumed that the bars began to give way at the smallest sections, and on this assumption the results shown in the following Table were obtained:—

Bar A.			Bar B.		
Number of Experiment.	Stress at Breaking Point.	Work Done on Bar.	Number of Experiment.	Stress at Breaking Point.	Work Done on Bar.
	Tons per Square Inch.	Inch-Tons.		Tons per Square Inch.	Inch-Tons.
I	18·18	4·05	1	18·41	4·12
II	17·22	5·04	2	18·62	4·86
III	15·91	3·92	3	17·19	3·50
IV	15·77	3·27	4	17·45	3·71
V	16·03	3·22	5	17·35	3·95
VI	..	4·23	6	..	3·68
VII	16·93	3·62	7	16·00	3·34
VIII	15·93	4·17	8	17·76	4·03
IX	16·71	3·73	9	17·98	3·35
X	15·71	2·99	10	16·92	3·10
XI	16·37	3·38	11	..	3·07
XII	15·69	2·92	12	17·26	3·24
XIII	16·87	3·74	13	17·29	3·48
XIV	17·20	3·34	14	17·33	3·47
XV	16·63	2·70	15	16·91	2·87
XVI	17·09	2·08	16	17·17	2·90
XVII	18·45	2·80	17	16·69	2·94
XVIII	17·51	2·38	18	16·42	2·66
XIX	15·90	2·71	19	18·79	3·40
XX	19·88	2·97	20	17·50	1·72
XXI	16·63	2·17	21	19·60	2·44
XXII	18·10	2·48	22	17·01	2·44
XXIII	23·20	2·10	23	16·59	2·38
XXIV	17·00	2·10	24	16·59	2·56
XXV	17·00	2·44	25	15·67	2·05
XXVI	20·10	2·11	26	16·31	2·52
XXVII	19·07	2·15	27	17·31	1·93
XXVIII	17·66	2·27	28	12·10	1·86
XXIX	17·59	1·75	29	15·62	2·16
XXX	19·04	1·83	30	17·25	1·85
XXXI	16·50	1·54	31	20·17	2·13
XXXII	21·83	1·88	32	18·42	2·92
XXXIII	19·11	1·89	33	16·02	2·50
XXXIV	22·79	2·64	34	20·97	1·39
XXXV	20·38	1·96	35	18·37	1·98
XXXVI	14·10	1·39	36	..	1·48
XXXVII	15·54	1·22	37	17·47	0·96
			38	..	1·66
	Total . .	101·18	39	18·92	1·22
				Total . .	105·82

The successive breaking-down points of the bars A and B were plotted at regular intervals on a vertical scale of 2 tons to the inch.

The broken line on *Fig. 4* represents the results obtained for bar A, while the corresponding full line is for bar B. It will be seen that the curves drop sharply at the commencement, from a value somewhat above 18 tons to a value oscillating about a mean of 17 tons, and up to the end of the sixteenth experiment this average value is fairly maintained; a rise then commences, reaching a maximum at the end of the twentieth experiment where the mean value is 18·7 tons. The mean curve then falls to the end of the twenty-fifth experiment, the mean value at that point being 16·4 tons. From this point to the end of the thirtieth experiment the mean values oscillate between 16·4 tons

Fig. 4.



and 18 tons and finally rise considerably higher. As the bar lengthens during the process it deviates more and more from its original form, and the extensions become more and more local. This effect adds itself to the change produced by the successive extensions and annealings, and it is difficult to allow for it; but from the results obtained it seems clear that with mild steel of this character the breaking-down point will rise considerably before final rupture takes place. An examination of the bars themselves indicated considerable hardness and brittleness.

Determination of the Work done on a Bar broken under ordinary conditions compared with the Work done on a similar Bar broken under the conditions stated above.—The work done on the bars was derived from the areas of the stress-strain diagrams by the formula.

$$\text{Work in inch-tons} = \frac{\text{area of diagram in square inches}}{x\,y},$$

where x inches = 1 inch of extension on the horizontal scale,
y inches = 1 ton on the vertical scale.

The work done on bars A and B at each operation is given in the Table above, whence :—

The total work done on bar A = 101·18 inch-tons ;
„ „ „ B = 105·82 „
„ „ „ C = 201·7 „

and

$$\frac{\text{Work done on bar A}}{\text{Work done on bar C}} = \frac{101 \cdot 8}{201 \cdot 7} = 0 \cdot 505 \; ;$$

$$\frac{\text{Work done on bar B}}{\text{Work done on bar C}} = \frac{105 \cdot 82}{201 \cdot 7} = 0 \cdot 524.$$

These results are in fair accord, and show that the work done on each of the bars A and B, when stretched from 10 inches to approximately 20 inches by successive steps of 0·25 inch and annealed after each operation, is about half that done on an exactly similar bar broken in the testing-machine in the ordinary way. It appears, therefore, that with mild steel bars subjected to tensile stress followed by annealing under the conditions described, that :—

(1) The total extension is about four times that of a bar broken in the ordinary manner.

(2) The breaking-down stress is of an approximately uniform value during the first stage when the bar has not deviated much from its original form, followed by a considerable divergence, the general tendency of which is to a considerable rise in value.

(3) The work done on a bar under the given conditions is approximately one-half of that done upon a bar broken under tensile stress in the ordinary manner.

Through the kindness of Mr. F. W. Webb, M. Inst. C.E., the Author was enabled to commence the experiments in the Testing House at Crewe Works; they were afterwards carried on in the Fulton Laboratory, Edinburgh University, under Professor G. F. Armstrong, M. Inst. C.E.

The Paper is accompanied by four tracings, from which the Figures in the text have been prepared.

(*Paper No. 3109.*)

(*Abridged.*)

"Refuse Furnaces."

By George Watson, Assoc. M. Inst. C.E.

In the following Paper the subject of refuse destructors is considered in reference to three typical installations of the Horsfall type, at Oldham, Edinburgh and Bradford.

The term "Town Refuse" is generally applied to the rubbish collected from dwelling-houses, markets, slaughter-houses, shops and factories. Its nature varies widely in different towns, and in different localities in the same town, as well as with the season of the year. The refuse of Leeds and Oldham, for example, which is collected chiefly from large ash-pits, measures about 40 cubic feet to the ton, a considerable portion consisting of cinders. At Edinburgh, on the other hand, where it is collected dry daily, and is mixed with a certain quantity of street sweepings, it measures 80 cubic feet to the ton. The amount of labour required depends more upon the bulk of the material than upon its weight, and 1 ton of wet and heavy refuse may require the application of only half the amount of work that 1 ton of light and bulky material demands.

The temperature required for the destruction of septic poisons in the products of combustion, and therefore the minimum below which the gases escaping from the main flue must not be allowed to fall, has been stated by Professor Wanklyn, and others, to be about 1,250° F. The fluctuations of temperature, due to the intermittent nature of the operations, require the average temperature to be considerably higher, even where only the proper cremation of the fumes is aimed at. But when it is possible to utilize the heat of the waste gases, it becomes important to realize the highest attainable temperatures; and it seems likely that arrangements will be made for the development of the whole of the available energy in most of the destructor installations undertaken in future in the United Kingdom.

Town refuse contains, as a rule, only one-third by weight of combustible matter; one-third being moisture, and the remainder

is incombustible, and is withdrawn from the furnace as clinker. Not only is the residuum non-productive of energy, but in drawing it red hot from the furnace a considerable amount of heat is lost; this has been estimated by Messrs. T. S. McCallum and W. Naylor, Assoc. M. Inst. C.E.,[1] for the case of Royton, Lancs. (where there is 46 per cent. of residuum), at 34 thermal units per pound of refuse, even when the clinker was allowed to cool in the ash-pits to 500° F. If it be withdrawn at 1,800° F. the loss is correspondingly higher. They state the specific heat of clinker at 0·17, and, the final temperature being, say, 60° F. the heat lost by the withdrawal of the residuum (when, as is usual with the furnaces about to be described, it does not exceed 33 per cent. by weight) at 1,800° F. may be taken as 97 B.T.U. per pound of refuse. Again, the moisture in the refuse has to be evaporated, and the heat required for this purpose robs the furnace of approximately 265 units more per pound of refuse. The heat required to raise the vapour to the temperature of the furnace is largely recovered on its passing through the boiler. The formation and burning of water-gas probably does not take place with most of the water evaporated from the refuse, but only with the steam of the blast which actually passes through the burning fuel. The same authorities found by calorimeter tests that the refuse of Royton, as collected, developed 997 thermal units per pound. A large amount of unburned carbon was found in the clinker. The cinders, which form the most valuable part of the rubbish, from a heat-raising point of view, are apt to become surrounded with fine incombustible dust, which clogs the fire and protects them from its action. Wherever the refuse is poor and dusty, the performance is rendered still worse by the difficulty of getting the fire to reach the cinders.

In the furnaces to be described the attainment of high temperatures has been secured by the combustion of refuse alone, without the use of extraneous fuel. The Author's experience with these furnaces has been gained in towns with such varying circumstances as those prevailing in Oldham, Hamburg, Edinburgh and Bradford. To secure sufficiently high temperatures, not only is active combustion, resulting from a strong draught, necessary, but there must not be too large a volume of air admitted into the furnace, either through the grates, or through the charging and clinkering openings. The amount of working required in the

[1] Paper read before the Association of Municipal Engineers. *Surveyor*, 5 July, 1895.

furnace involves large openings into it, either at the charging or clinkering end, during not less than one-sixth of the whole time the furnace is in operation; and it has been found that a strong natural draught draws in such volumes of cold air through these openings as to keep the furnace constantly at a low temperature. Mr. William Horsfall, of Leeds, recognized this fact, and in the Horsfall furnaces forced draught is applied, while natural draught is reduced to a minimum. For this purpose fans were first employed, but they were soon abandoned in favour of steam-jets, and though the former have since been found more suitable for certain kinds of refuse, the latter have been applied in the larger number of instances. Wherever the refuse is sufficiently rich in carbon to maintain constantly a sufficiently high temperature to decompose the steam, and to form water-gas in the furnace, then steam-jet forced draught is preferred to fan blast, in spite of the fact that, with the same expenditure of steam, considerably more air can be delivered by means of an efficient fan than by even the most improved jet apparatus. The effect of the formation of water-gas in the furnace is no doubt of great value in carrying forward the combustion of the gases to a point in the system at which they have become thoroughly mixed. The water-gas is formed during the passage of the steam through the incandescent fuel on the grate; and its combustion takes place in due sequence, considerably further in the course of the products of combustion. Thus waste unburned gases are reached and burned which would otherwise escape. Clear flames 25 feet long from the surface of the fire are often observed in destructors of this type with steam blast. Further, certain gases combine better in the presence of vapour of water and of water-gas than alone. Tests made at Oldham, in 1895, with the old style of round nozzles, showed an expenditure of 270 lbs. of steam per cell per hour to give the required air-supply of 600 cubic feet, or 47 lbs. of air per minute at a pressure of 1⅛ inch of water. Experiments extending over short periods at Hamburg with flat nozzles showed about 88 lbs. of steam per cell per hour. The amount of steam used can only be kept moderate by very careful adjustment. In practice a steam consumption of about 100 lbs. per cell per hour, when burning up to 10 tons per 24 hours, ought not to be exceeded. In the 36-cell Horsfall destructor at Hamburg,[1] both

[1] "The Municipal Burning Works for Refuse on the Bullerdeich at Hamburg," by F. Andreas Meyer, Ober Ingenieur, Hamburg. Deutsche Vierteljahrschrift für offentliche Ger[illegible]ge, vol. xxix., part 3, 1897.

steam-jets and fans were installed, and after careful trial, it was decided to use the fans, which were found to require much less steam. While the amount of steam required for the jets was about 5½ I.HP. per cell, in ordinary working, the fan was found to require less than 1 I.HP. per cell. At Hamburg the refuse is so poor in carbon that probably the water-gas effect, previously referred to, does not exist, and, consequently, one of the main advantages of the steam-jet apparatus fails.

Analyses of the gases in a similar furnace, under natural draught and under the action of steam-jets, show that the steam draught has a powerful effect upon the combustion. The amount of carbonic acid without steam is only 2 per cent., whilst with steam half on it is 9 per cent., and with steam full on it is 14·5 per cent.

The greater part of the vapour of water given off by the refuse in drying does not actually pass through the incandescent portion of the fire, and is not subjected to the conditions necessary for the formation of water-gas. Further, the steam has an important effect by its power to cool and preserve the grate-bars and other ironwork in the furnace. The steam on escaping at a high pressure from the nozzles immediately condenses; then, coming into contact with the comparatively hot sides of the cast-iron air-boxes, which line the furnaces, and with the undersides of the grate-bars, it re-evaporates, and so cools the surfaces of the ironwork. Grate-bars have been taken from a furnace at Oldham, after 5 years' service, from which 5 inches of hot clinkers had been removed every 2 hours nearly every day except Sundays and holidays, during the whole time, apparently little the worse for wear.

Forced draught secures the advantage that, provided the ash-pit is kept tight, the draught is not affected by ill-fitting or partially closed furnace doors, nor by the chimney temperatures, and varies only with the thickness or solidity of the fuel on the grate, the air-supply being to some extent measured to the furnace. But the condition of the fire itself unfavourably affects the air-supply; since the air passes least freely through a fresh fire newly fed, when most air is required. This defect could only be completely overcome by some positive air-supply, such as that of an air-pump or compressor, which would be unaffected by the comparatively small changes in the resistance to the passage of the air through the fire.

To ensure the proper mixing of the gases from the new fires with those from older fires in active combustion before they are allowed to cool, it has been the practice to build the furnaces either in a continuous row, when single-row cells are used, or in

a block when "back-to-back" cells are used, and to place the boilers at the end of the block of furnaces and independently of them. By this arrangement any cooling of the gases is postponed until after they have become thoroughly mixed, and have traversed a considerable surface of hot brickwork. Any loss of heat by radiation is more than balanced by the gain resulting from perfect combustion. It is, further, more convenient to have the furnaces and boilers independent of each other, both for the proper bracing of the furnaces together, and for accessibility of the boilers for inspection, cleaning and repairs. Each cell should not be considered separately, but the block of furnaces should be regarded as a whole, and the boilers should be placed as near to it as possible.

In addition to the "plenum" system, Mr. Horsfall also introduced the front exhaust for the products of combustion; and he thus secured that all the vapour given off by the refuse in drying is subjected to the greatest heat of the furnace. The gases given off by the newly charged refuse at the back of the furnace are caused to pass over practically the whole surface of the fire before escaping, and as the temperatures maintained are such as to make the crown of the furnace glow, the escaping gases are also subjected to a fierce heat radiated from above. By working at the highest attainable temperatures, it is possible to store such an amount of heat in the brickwork as will carry over the time of charging and clinkering, and the heat radiated from the arch of the furnace sufficiently cremates the escaping gases until the fire again burns up. Tests at Oldham showed the temperature of the vent-holes during the operation of clinkering to be 1,773° F., and the temperature of the furnace itself, taken a quarter of an hour after clinkering and 5 minutes after recharging was 1,800° F. A further safeguard lies in the general arrangement of the furnaces, whereby the gases from new and old fires are mixed.

The front exhaust, when arranged so that the openings are placed in the top of the furnace arch, also tends to prevent the escape of dust, as it would have to rise to a considerable height before being caught in the current of the draught. The strength of the blast ought not to be such as to blow dust up from the surface of the fire to the roof of the furnace. It is, however, also limited by the desirable rate of combustion per square foot of grate per hour, which has a most important bearing on economy of working. In the case of the Powderhall destructor at Edinburgh, a further precaution was taken against nuisance from dust by providing a special dust-catcher. This consists of an outer annular

chamber and an inner circular chamber or well, Fig. 6, Plate 8. The gases enter the outer chamber tangentially and swirl rapidly round it, thereby throwing off the greater part of the suspended dust against the outer wall. Their only means of exit from the annular chamber are vaulted openings in the upper part leading into the inner chamber or well. Here the gases have to pass downwards, and two outlets are provided near the bottom, one leading to the boiler and the other to the by-pass flue. Cleaning-doors are provided for removing the dust, which accumulates in the pockets formed at the bottom of each chamber, and the considerable amount recovered shows the value of such an apparatus, even when the furnace itself is specially designed to prevent the escape of dust. The refuse of Edinburgh is, however, of a specially dry and dusty character. The temperature within this dust-catcher is constantly 1,800° F., and in new installations of such an apparatus, in cases where steam is to be raised and utilized, it would be preferably placed between the boiler and the chimney rather than in front of the boiler. The chimney at Powderhall, as now working, is so free from smoke and dust that neighbouring residents have occasionally imagined the plant to be idle when it was in full operation.

Horsfall furnaces may be classified as of the single-row type at Oldham, Figs. 1, 2, and 3, and of the double or "back-to-back" type at Hamburg, Edinburgh, Figs. 4, 5, and 6, and Bradford, Figs. 7, Plate 8. In the single-row type the furnaces or cells are placed side by side in a continuous block, all the clinkering-floors being in front and all the feeding-doors at the back. In front of the furnaces the clinkering-floor is on the ground level for both types of cells, and the dead plates are 4 feet above the clinkering-floors. The grate-bars are inclined from the dead plates at about 1 in 5. In the single-row type the feeding is performed from the back through suitable sliding or hinged doors by means of the shovel, while in the back-to-back type feeding-holes are formed on the top or deck of the furnaces, one being common to two furnaces, sloping away from it on either side. In the single row back-feeding type, the feeding operation is performed at a much lower level than in the back-to-back type, when it is necessarily performed at the top of the furnace. In the single-row cell with a sloping grate and hearth at the back of the grate, the sill of the feeding-door is placed about 6 feet 9 inches from the ground line. The charging platform for back-feeding is most conveniently placed 18 inches below the sill of the feeding-dorr, as the stoker can then shovel in the refuse without lifting it

unduly, while he can also see the whole length of the furnace without too much bending of his back.

As the furnaces are generally worked throughout the 24 hours, while the refuse is only collected during about 8 hours, it is necessary to provide storage for two-thirds of the refuse burned, either on the deck of the furnaces for the back-to-back type, or on the charging platform at the back in the single-row type. It saves labour to store the refuse in a high heap, as near as possible to the feeding-hole, rather than to provide a wide space for it, from which a large portion would have to be carried some distance. In most cases the tipping floor should be a clear height of 6 feet above the deck of the furnaces, or the charging platform, as the case may be. Therefore for single-row furnaces, having a charging platform 5 feet 3 inches from the ground line, the tipping platform requires to be 11 feet 3 inches from the ground line in order to give the desired convenience in handling the refuse. The furnaces are about 12 feet high from floor-level, and therefore with the back-to-back type the tipping platform must be about 18 feet above ground line. When a level site is adopted, the inclined road for the carts to pass up to the tipping platform has to be formed. The gradient for such heavy loads should not exceed 1 in 20; and therefore the length of road for the single-row system would be 225 feet, while for the back-to-back cells it would require to be 360 feet. Another point in favour of the single row is that the stored refuse rests on a cool platform, quite away from the furnaces, instead of lying on the hot deck. At Edinburgh and Bradford, however, the heat of the deck is reduced somewhat by the use of air-conduits communicating with the inlet to the blast and formed by means of drain tiles laid at intervals in the concrete forming the deck, Figs. 5 and 7, Plate 8. In cases where lifts are employed to raise the refuse to the deck of the furnaces the difference of height becomes comparatively unimportant; but lifts have seldom been adopted outside the metropolis, where the land necessary for the inclined road is not generally available. The natural contour of the site sometimes permits sufficient difference of level between the tipping and clinkering floors without expensive works. The type of furnace to be adopted depends mainly upon the contour of the site, but also to a great extent upon the number of cells required. In most cases the single-row type will be least expensive for any number of cells up to five, and for larger numbers of cells the back-to-back type is preferable. There is practically no difference between the two systems in regard to economy of labour.

On the back-to-back system the refuse, being tipped out of the carts, lies in a heap on the deck of the furnaces near to the feeding-hole, but not near enough to block it. The following operations are then necessary for charging:—(1) The feeding-hole, Figs. 5 and 7, Plate 8, which is practically a square pit with a flat bottom and two arched openings in its opposite sides leading into the two furnaces which it serves, must be opened. If this pit be merely filled with refuse, the material lies on the flat bottom or table, and, piling up, chokes both openings, thus closing the furnaces. No door is used; but if it be desired to feed either of the furnaces, the refuse is pushed through one of the holes in the side of the pit and, as it were, off the edge of the table, when it falls into the furnace and leaves an opening for the introduction of the charge. This is done by means of a light poker with three prongs, *a*, *Figs. 8*. The opening having been made, the refuse is pulled down from the heap with a muck-rake and pushed into the furnace with the prong, cinders and dusty material being necessarily inserted with a shovel. The pushing down with the prong is by far the heaviest part of the labour of feeding on this system, as the charging opening soon fills unless the stuff is continually pushed far into the furnace. When the furnace is sufficiently charged, the pit is again filled, and thereby the opening into the furnace is closed.

On the single-row system the refuse lies in a heap on the charging platform; but in order to leave room for the stoker to stand between the refuse and the furnaces, it is a little further from his reach than it is on the deck-feeding system. The muck-rake has occasionally to be used here also, but most of the labour is done with the shovel, the material continually falling down as the foot of the heap is shovelled away. The heavy labour of pushing in is avoided on this system, as it is only necessary to open the door, and then the refuse is thrown on to any part of the furnace, the stoker having a complete view of it, and the first spreading of the fire is also done by throwing from the back, more refuse afterwards being heaped up on the drying hearth ready for pulling down on to the fire. When the operation is complete, the furnace is again closed by the door. The shovelling in through a back door is no doubt somewhat heavier labour than the feeding from the deck, but with the top charging the refuse cannot be spread over the fire, but is merely pushed blindly in, so that more work remains to be done at the front on that system than with the back feed. Moreover, with the front exhaust for the hot gases, the heat is concentrated in the front of the furnace, leaving the back part, where the refuse is introduced compara-

tively cool. This tends to prevent the furnace from smoking during the charging operations, and further it is advisable to do as large a proportion of the work as possible from the cool end of the furnace.

With the single-row type, where the charging platform is much lower than the deck of the furnace, it is most convenient for one man to do the feeding and clinkering of his own two or three cells, thus avoiding division of responsibility for their working. But where the furnaces are charged on the top, it is usual to station a certain number of men on the deck to feed, while the stokers below only work the fires. Signals are then necessary between the stokers below and the men above, by such means as speaking-tubes, bells, or semaphores, to indicate when each furnace has been clinkered, and is ready for filling. The labour of feeding requires less skill, and is sometimes paid for at a lower rate than that of the furnace-men proper.

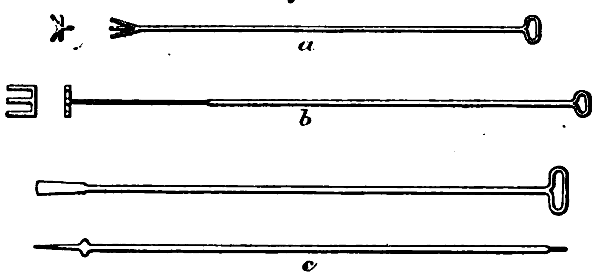
The work at the front of the fire is similar for both types of furnace; and consists in pulling the refuse forward and spreading it over the fire with a long-handled iron rake, *b*, *Figs. 8*, at the commencement of the operation, and at intervals afterwards, as the fire burns down; and in clinkering the fire at the stated times. The large proportion of clinker (being generally about one-third by weight of the refuse) makes the work of clinkering one of the main features of the reduction process, and it is performed at stated intervals, absolute punctuality being insisted upon at all well-managed destructors. The furnaces are worked in rotation, to ensure that there are never two new fires at the same time, and thus, if any unburned fumes escape from one furnace, they are cremated in the main flue by the hot gases from the others.

The frequency of clinkering depends entirely upon the rate of working which is desired; and it is found that from 8 tons to 10 tons per cell per 24 hours is the most economical rate of working for a standard Horsfall cell having 30 square feet of grate area. Higher rates can be obtained by applying a strong blast pressure in the ash-pits, but the fires then burn into holes every minute or two, and have to be continually stirred and raked over. Then also clinkering must be more frequently performed, and the amount of refuse dealt with per man per shift falls rapidly, as the rate of burning increases above, say, 10 tons per cell per 24 hours. Eight tons can be burned by clinkering every 2 hours, and by pulling down twice or three times between each clinkering; and, at this rate, one man can work three cells, both charging and clinkering. If the shifts are 8 hours each, and the pay *5s.* per shift, the

cost of working is about $7\frac{1}{2}d.$ per ton burned; while the length of time between clinkerings is sufficient to ensure that even the least combustible portions of the refuse are thoroughly burned, and that the clinker is of the best quality. This result can be obtained with an average blast pressure of $\frac{7}{8}$ inch of water and a fire averaging 10 inches thick, the slab of clinker, formed upon the grate at the end of the operation, being about 5 inches thick.

The residuum is about one-fourth of the bulk of the original refuse, so that a clinker 5 inches thick represents a thickness of refuse of 20 inches. The amount of refuse pulled on, in, say, two operations between each clinkering and charging, would then be a layer of about 5 inches thick each time. If, on the other hand, it is sought to burn as much as possible in each cell per 24 hours, with a blast pressure of say $2\frac{1}{2}$ inches to 3 inches of water in the ash-pits, and clinkering every $\frac{1}{2}$ hour, as much as 15 tons can

Figs. 8.



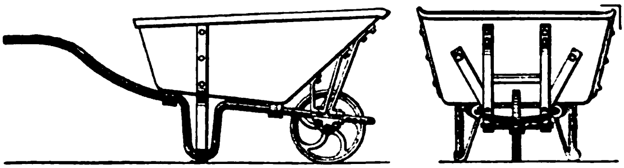
Scale, $\frac{1}{4}$ inch = 1 foot.

be burned in each cell per 24 hours, when there is one man to each cell in each shift. At this rate, however, each man only burns 5 tons in his 8 hours' shift at a cost for labour of 1*s.* per ton, as against $7\frac{1}{2}d.$ per ton at the more moderate rate of working. Moreover half an hour in the furnace is not long enough to burn the less combustible parts of the refuse, and the clinker will not be so completely fused. Further, the excessive blast blows quantities of fine dust up off the surface of the fire, which adhere to the roof of the furnaces and flues, or otherwise are sent out of the chimney, in either case a very objectionable matter. If the blast is kept strong enough to maintain the supply of dust, it accumulates very rapidly, and forms inconvenient excrescences, which are sometimes called "stalactites," and which have to be frequently broken off and removed, thus abrading and re-exposing the surface of the brick-work.

Experiments comparing the results of different rates of burning were made at Leeds, under the supervision of Dr. Spottiswoode Cameron, Mr. George Darley and Mr. Putnam, in 1894,[1] in which as much as 26¾ tons were burned in a single Horsfall cell, having 35 square feet of grate surface in 24 hours. Considering the great diversity in the rate of wages paid to refuse stokers, the performance of different furnaces should be compared as tons per man per 8 hours' shift, or, say, tons per man per hour. It requires considerable skill on the part of the stoker to break up the mass of clinker, and to remove the large lumps from the furnace; first turning them over with the chisel bar, so as to shake off their upper surface the red-hot ashes which must be left in the furnace in order to start the new fire.

The difficulty of properly and quickly igniting the new charge is one of the greatest obstacles to mechanical stoking. The refuse is poor fuel, and it was found by Mr. Horsfall, in some experiments he performed at Leeds, that it is very difficult to get the fire to

Figs. 9.



Scale, ⅜ inch = 1 foot.

creep back, as the refuse creeps forward; and the only possible method is to traverse the bars so slowly that the duty of the furnaces becomes insignificant. Moreover the motion of the fire-bars tends to riddle through the small red-hot cinders, which are necessary for lighting the new charge. Mechanical feeding, as distinguished from mechanical clinkering, was performed successfully by Mr. Horsfall; but in securing that result the feeding was intermittent after each clinkering, and this system of charging and clinkering is likely to survive in regard to the burning of refuse, even if mechanical appliances come into general use.

The tools for clinkering become very hot, and must therefore be stiff to prevent bending, *a*, *b and c*, *Figs. 8*. It has been found an improvement to make the handles of these tools of steel tube. The clinker is allowed to fall direct into an iron barrow, *Figs. 9*, placed below the clinkering door, in front of the furnace, and is then

[1] *Sanitary Record*, 9 October, 1896.

wheeled out to the cooling floor and tipped to cool. It is usual to turn off the blast during each of the operations of charging and clinkering. The principal use of the drying hearth at the back of the furnace will be apparent from the above description. Even if it be not required for drying a portion of the refuse before it is drawn on to the fire, it is necessary for holding a reserve of refuse to be pulled on between the operations of clinkering.

The amount of refuse varies greatly in different districts, but approximately ¼ ton per head of the population per annum will be collected. From 10,000 inhabitants, therefore, 2,500 tons per annum will be collected; and taking 300 working days in a year, there will be just over 8 tons to dispose of daily. This would necessitate one destructor cell to each 10,000 inhabitants and, in an extensive experience, this ratio is found a fairly suitable basis of calculation where precise data are not obtainable. Where 6 days a week only are worked, it is usual to bank up on Saturday night at 10 o'clock, and to start again at 10 o'clock on Sunday night, and it is found that the fires will remain alive for even longer periods than this when necessary.

The Oldham[1] destructor, which was the first installation (apart from a small experimental furnace) erected on the Horsfall system, is of the single-row type, while those at Hamburg, Edinburgh,[2] and Bradford[3] are back to back. The site at Rhodes Bank is on a level with the adjacent street, and is about 1,827 square yards in area, including the space on which the new boiler is placed, and it immediately adjoins the Horse and Provender Committee's premises on the one side and the central electric lighting station, also belonging to the Corporation, on the other, Fig. 1, Plate 8. Steam is drawn from the destructor to both of these departments. The plant is surrounded on all sides by rising ground to a height of 100 feet, or thereabouts, quite covered with houses, and it is situated only a short distance from the Town Hall and the main business part of the town. Inhabited houses line the side of the street opposite to the destructor. In the first instance a group of six cells was built and set to work in February, 1891. The boiler was of the multitubular type, 7 feet in diameter by 12 feet long, with 3-inch tubes. A conduit formed of old iron boiler-flues, and having an effective area of about 9½ square feet, led the gases to the chimney already

[1] See *Engineering* for 22 January, 1897.
[2] See *The Engineer* for 26 August, 1898.
[3] See *Engineering* for 12 August, 1898.

existing on the site, Fig. 1, Plate 8. The tipping-floor was formed by paving the top of the furnaces so that they were subjected to vibration from heavy carts; and common local fire-bricks were used in the linings. The arches of the furnaces were very flat, and the main flue was formed by a flat arch traversing over the top of the furnaces lengthwise. The temperatures reached were far in excess of the anticipations of the inventor, the furnaces and flues being constantly at a glowing red heat, and sometimes exceeding 2,000° F.[1] In spite of these severe conditions the plant worked well, with practically no repairs, for 17 months; but the heat and vibration had their effect, and a short length of the flat arch forming the main flue over the furnaces eventually failed, thus causing a stoppage of the plant. The six furnaces were then reconstructed with the main flue below the feeding hearths of the furnaces instead of over them; ordinary local fire-bricks being again used for the linings. Advantage was taken of the stoppage to make a new inclined road, Fig. 1, Plate 8, with a more moderate gradient than the old one, and also to lower the feeding platform to its present position and to substitute sliding feeding-doors for the old method of feeding through a kind of funnel, which was closed by choking it with refuse. The feeding platform is 11 feet wide by 6 feet below the level of the tipping floor. The bin so formed has a capacity of about 260 cubic feet behind each furnace, when the muck is well heaped up, and as the Oldham refuse measures 40 cubic feet to the ton, this is equal to a storage of about 6½ tons behind each furnace, or, say, two-thirds of the maximum amount required to be burned in 24 hours.

After 2 years and 10 months' working repairs became necessary to the six-cell group; and they were then further improved by the addition of side air-boxes, and the upper portion of them was reconstructed to their present form. In the meantime the group of four cells had been added at the end of the existing tipping platform, and these differed in some respects from the six-cell group as originally constructed. Improved rocking grate-bars of the Settle type with finer spaces (about $\frac{5}{16}$ inch) were put in; and for the linings a more refractory brick, containing about 70 per cent. of silica, was used. The furnace arches were built of large special blocks throughout; those in the front part of the arches having round vents forming the exhaust for the products of combustion. The steam blast was of the round

[1] See also *Engineering* for 16 and 30 September, 1892.

nozzle type; but an improved form of trumpet was used, and two were applied to each furnace instead of one as before. Hardened tool-steel nozzles were used instead of brass, which had been found to wear larger very rapidly. While these alterations gave an improvement in efficiency, the noise caused by the blast was not obviated. It has been found in testing these four cells that if the two blowers in the ash-pit are not working quite equally, owing to a slight difference in the size of the orifices, or to a readier access for the steam to one or the other, or to the action of the wind, the stronger blower overbalances the weak one, causing it to deliver little or no air, or even to blow back. This can be to some extent avoided by so designing the trumpets that the velocity of the air delivered is considerably above that necessary to produce the required pressure in the ash-pits; but the difficulty has been overcome in later constructions by the adoption of adjustable nozzles, which can be set to exactly balance one another.

At the time that the six-cell group again needed repairs, after nearly 3 years' continuous working, it had become evident that the old chimney, and the main flue leading thereto, were inadequate to deal with the gases from the ten cells, in addition to the electric-light station boilers, and it was therefore decided to build a new chimney for the destructor. It had been demonstrated by repeated trials that a large amount of power was available from the destructor gases, and the adoption of a high-pressure Lancashire boiler, 8 feet in diameter by 30 feet long, in place of the old multitubular boiler was resolved upon by the Corporation; and also the addition of a Green's fuel economiser. The work was accordingly put in hand, together with the repair and improvement of the six-cell group, which was damped down, and the four-cell group was coupled direct to the existing multitubular boiler independently by means of a flue of rectangular section, 2 feet 6 inches wide, by 4 feet 3 inches high, and 54 feet long from end of furnaces to boiler front. This flue was built with hollow walls, forming an unventilated air-space, for the purpose of preventing loss of heat by radiation. The inner wall of fire-brick, and the outer wall of common brick, were each 4½ inches thick, and the space between was about 2 inches. The flue was covered with 6-inch fire-brick quarries. The object was to keep the old boiler going as long as possible, and to maintain steam for the blast, one mortar-mill, and for the machinery in the horse and provender department, even while the rest of the plant was being reconstructed. It was found that the drop in

temperature from one end of the flue to the other averaged 505° F.; being 2,090° F. at the furnace end, and 1,585° F. at the boiler front, and the steam was easily maintained at 80 lbs. pressure for all purposes. A supply of steam equal to about 50 I.HP. was given right up to the time when the old boiler had to be removed to complete the seating of the new one, and even after that the four-cell group was kept going under natural draught by means of a temporary flue connection direct to the old chimney. Also the six-cell group was dried in a similar manner after reconstruction by means of natural draught from the old chimney, while the new boiler-seating and flues were being constructed. The construction of the new boiler and the chimney and flues was meanwhile proceeding. The chimney is round, 120 feet high, with an inner shell of fire-brick and an air-space, both extending to the top, the air-space being provided with grates at bottom and top for ventilation; it is thus kept cool, and no cracks have appeared. The cap is formed entirely of brick-work, and its upper surface is curved so as to direct the impinging wind in an upward direction.

The economizer consists of ninety-six tubes without scrapers, which have proved unnecessary owing to the absence of soot from the furnace gases. The by-pass from the economizer had to be carried underneath it, Fig. 2, Plate 8, and at the point where the flues part two dampers are hung on the same vertical spindle, one below the other, at right angles to one another, so that when one is open the other is closed. The dampers throughout the works are of cast iron, with carefully proportioned rims, and ribs tapering from the centre, so as to avoid distortion in the heat. They are hung on ball-bearings, and provided with a toothed rack and clip to fix them in any position. The dampers in the flues behind the boiler have stood well, and can be turned with a very slight pressure of the hand; but those in the greatest heat have not been successful, as they are found to warp and crack after 6 months' use. ✓Even if a damper is made which will draw out of the heat when not in use, it is found to warp and jam the first time it is let down; and also as it is generally found that the damper is required to be only partially open for long periods, the iron framework is soon burned away. Rods are provided for regulating the steam blast, either from the back or the front of the furnaces. The blast apparatus adopted is of the type devised by Mr. C. W. James, in conjunction with the Author, in which the steam-nozzle has a flat adjustable orifice from which a ribbon instead of a plug of steam issues. If the air is carried

through the trumpet, mainly by surface friction between the issuing jet of steam and the surrounding air, then a flat jet should have a greater efficiency than a round one of comparatively large diameter. This is found to be the case at Oldham and elsewhere.

Dry steam is secured by wire-drawing it through a reducing valve from 130 lbs., which is the normal boiler-pressure, down to 70 lbs. per square inch, which is found to be a more economical working pressure for the jets. There are two blast nozzles and trumpets to each furnace, Fig. 3, Plate 8, one at each side, delivering into the side boxes, and they draw their air from the tunnel beneath the feeding-bin, and thus the noise of the jets is so muffled as to cease to be any inconvenience. The side boxes have separate face-plates, which can be renewed from time to time, as they burn out. It is found, however, that the steam and cold air passing behind them protects them so efficiently from being overheated that only fifteen new plates have been required in the 2 years and 2 months, during which these furnaces have been at work. As each furnace contains eight plates, their renewal is only a trifling expense compared with the cost of repairing brickwork sides. These side boxes have the great advantage that they prevent the hot clinker from sticking to the sides of the furnace, as it always does to brickwork, bringing away pieces of the brick with it when it is removed, and thus undermining the furnace crown, and letting it fall long before it is really worn out. The side boxes, besides preventing this action, render the operation of removing the clinker easier, and also heat the air in its passage. The vents for the air are all beneath the bars, and are so arranged as to deliver the air-supply very evenly into the ash-pit.

The ash-pit temperature, with the old system of steam blast delivered direct into it, was 130° F., while with the cast-iron side boxes it is very much higher. At Edinburgh and Bradford, where the air is first heated to some extent by its passage along the hot-air duct, before reaching the side boxes (in which it is further heated) the ash-pit temperatures are found to be about 400° F. The clinker doors of all the ten furnaces are of the fourfold hinged type, with a division in the middle. This arrangement makes it somewhat more difficult to withdraw the clinker than when doors the full width of the furnace are employed, and it is also open to the same objection as the old-fashioned flap door, that the open door exposes a red-hot baffle plate which radiates its heat on the stoker's face. These considerations led to the subsequent

adoption at Bradford of a full-width sliding door with vertical lift and balance weight, Fig. 7. Plate 8. This door is lined with $4\frac{1}{2}$ inches of firebrick and consequently is always cool, and up to the present it is found quite satisfactory. The staying of the furnaces was carefully arranged with tie-bolts only at the top and bottom and vertical backstays of H iron, pressing the longitudinal stays to the furnace fronts. In order to make these backstays bind against the middle of the furnace, they were given an inward camber, and, when nipped up, they were pulled straight by the tie-bolts. The ten furnaces had eventually to be stopped for a fortnight, while the temporary flues were removed, and the new mattress chamber and permanent flue-work constructed. The mattress chamber is for cremating bulky articles such as baskets, carcases and worn out bedding, and is simply an enlargement of the main flue placed at the end of the six furnaces, and provided with a large opening covered by iron-plate doors on the deck level, and also with a bottom cleaning-door for removing the residuum. The passage of the gases through it is found quite effective in destroying the articles put in.

During the 2 years since the completion of these works, the whole plant has continued to work satisfactorily. The destructor began to supply steam regularly to the electric-light station in the middle of March, 1896, at the required pressure of 130 lbs. per square inch, and to the extent of about 115 I.HP. (reckoning 20 lbs. steam per I.HP. per hour), this being the first instance of the supply of high-pressure steam raised by the burning of refuse to a central electric lighting station for public supply. The installation of a second high-pressure Lancashire boiler, of the same dimensions as the fist, is the only alteration of the plant which has since been made, and the construction and setting of it, and the necessary flues, was carried on without interfering with the working of the existing plant until February, 1898, when the four-cell group was stopped for a few days in order to couple it to the new boiler. As the plant now stands, either boiler can be coupled so as to perform any part of the work; and they join in contributing the whole of their steam to the electricity station whenever required. The boiler of the four-cell group is provided with a separate Kennedy hot-water meter, and its output is registered daily. Either boiler can be fed by a feed-pump, or injector, or both, either with hot water through the economizer or with cold water from the town main or from the reservoir. The hot gases from both groups join in front of the economizer, through which the whole or any proportion of them can be passed.

The capital outlay upon the whole installation has been as follows:—

	£	s.	d.
Land	2,175	10	0
Works	7,699	8	0
Total . . .	9,874	18	0

The cost of repairs averages 2·5 per cent. upon the total capital outlay in works, apart from land, from the year 1891 to 1896 inclusive.

Even more favourable results, as regards maintenance, are being gained with Horsfall furnaces elsewhere, and it may safely be laid down that 5 per cent. on the total capital would be sufficient to cover depreciation as well as repairs on a well-constructed plant, or say 10 per cent. on the cost of furnaces, boilers and flues taken separately.

The cost per ton burned in stokers' wages for the past 12 months is 9¾*d.*; the men being paid 30*s.* per week of six 8-hour days. The nett cost per ton burned, after crediting receipts for mortar and £65 a year saved to the Horse and Provender Committee in coal alone, by using the steam for chaff-cutting, &c., is given as 1*s.* 1½*d.* per ton burned.

The Author's estimate of the saving in coal to the electricity station, apart from any saving there may be in stokers' wages, is 6·3*d.* per ton of refuse burned, thus reducing the nett cost of burning the refuse to 7·2*d.* per ton for all charges.

The following approximate statement shows the steam now used at Oldham, it being all at about 130 lbs. pressure per square inch:—

	Lbs. per Hour.
Steam from new boiler to electricity station	2,985
„ to horse and provender department, say 20 I.HP. = say	400
„ to two mortar-mills, say 50 I.HP. = say	1,000
„ from old boiler to electricity station, say, in daytime	480
„ jets of all ten cells, say	1,800
Total	6,665

When the mortar-mills and the machinery in the horse and provender department are stopped at night the amount of steam available for the electricity works is 4,865 lbs. per hour, or, reckoning 20 lbs. steam per I.HP. per hour, say 240 I.HP. Thus it appears that about 70 I.HP. is used for mortar grinding, &c., during the day of 9 hours, in addition to a small amount for

running the day load, and charging the accumulators at the electricity station, while, say, 240 I.HP. can be used for, say, 6 hours at night.

In considering these results, it should be borne in mind that the plant was not originally laid out for steam-raising, and that the Oldham destructor was not only the first upon the Horsfall system supplied to any corporation, but was actually the first high-temperature installation erected anywhere.

The most recent example of the back-to-back type of furnace is the twelve-cell destructor at Hammerton Street, Bradford, Figs. 7, Plate 8, of which six cells started working on the 20th September 1897, the other six being set to work on the 31st January, 1898. In these furnaces two blast flues or air-ducts are built, one at each side of the main flue, and divided therefrom by a 14-inch wall. These flues communicate through suitable openings with the side air-boxes, and valves are provided for starting and stopping the blast to each furnace. This arrangement of furnace is to a great extent on the regenerative principle. Any heat radiated from the main flue is received at the top by the refuse on the drying hearth, and at the side it is received by the air for the blast, which is warmed there and in its passage through the side boxes to 400° F. Thus practically all the heat radiated from the main flue is carried back into the furnaces. The air is delivered into each blast flue by a large steam-jet apparatus, which is built into the down-take flue at the end of the furnaces. There are two down-takes, one for each blast flue. At the top of the down-takes are iron hoods, so arranged as to draw the whole of the air-supply from the deck of the furnaces, thus tending to keep it free from any smell caused by refuse arriving in a stinking condition. The furnaces are fitted with fixed straight grate-bars having fine spaces ($\frac{3}{16}$ inch), as are also those at Edinburgh, and much better results have been attained than with the rocking bars hitherto used. With these bars the air is much better distributed and the fire does not burn into holes so quickly as with wider-spaced bars; and another great advantage is that the amount of fine ashes is enormously reduced. The frequent removal of fine ashes from the ash-pits, which is found necessary with large-spaced rocking-bars is a most inconvenient operation and greatly increases the labour of working the furnaces. The grates are 5 feet wide by 6 feet long.

The cost of labour in working the twelve cells is, at the date of writing, returned officially as $5 \cdot 6d.$ per ton, which is the lowest figure yet recorded of any destructor so far as the Author is aware.

The men work 12 hours a day, and are paid 28*s.* a week for 5½ working days. There are twelve men, six in each shift, three working one block of six cells and three the other; one filling and two stoking each block.

The amount burned is 10 tons per cell per 24 hours, or, say, 120 tons per day total. The blast pressure in the ash-pits is about 1⅛ inch average.

The Author begs to acknowledge his great indebtedness to his Worship the Mayor of Oldham (Mr. Alderman Waddington) for permission to give official figures regarding the cost and working of the plant; and to Mr. W. Jessop, Superintendent of the Ashes Department, for his kind assistance in furnishing the information and in granting facilities for trials from time to time; to Dr. A. B. W. Kennedy, M. Inst. C.E., Consulting Electrical Engineer to the Corporation, and to Mr. T. Wilmot Newington, Borough Electrical Engineer; also to Mr. J. H. Cox, M. Inst. C.E., City Surveyor of Bradford, who supervised the construction of the destructor, and Mr. J. McTaggert, Engineer and Manager, for the facilities and valuable information kindly afforded.

The Paper is accompanied by nine drawings, from which Plate 8 and the Figures in the text have been prepared, and by Appendixes referring to trials of installations embodying the principles described.

OBITUARY.

Sir WILLIAM ANDERSON, K.C.B., F.R.S., D.C.L., was the fourth son of Mr. John Anderson, a member of the firm of Matthews, Anderson and Company, bankers and merchants, of St. Petersburg, and was born in that city on the 5th January, 1834. He received his elementary education in St. Petersburg at the High Commercial School, and even then showed great talent, becoming head of the school, and carrying off not only the silver medal but the freedom of the city. St. Petersburg is a very cosmopolitan place, and he thus enjoyed great facilities for acquiring languages, which, with his natural linguistic talent, he was not slow to make the most of. Thus, on leaving Russia to finish his education in England in the year 1849, he was a proficient in English, Russian, German and French. He had, in fact, two mother tongues, Russian and English, and used either indiscriminately. Even many years after he used to say that he often thought in Russian. He employed his knowledge of that language with great advantage to the Institution by translating and abstracting for the Proceedings articles of interest that appeared in the Russian technical journals, among which may be particularly noticed Chernoff's researches on steel.[1]

In 1849 he became a student in the Applied Sciences Department at King's College, London, and passed through the course with distinction, becoming an Associate on leaving. He used to tell with pride how he and his friends managed to make the iron castings for some small engines they had in hand. There was no steam-power to work the cupola blast fan, and it had to be done by manual labour, so that the making of a casting was not an easy thing to carry out. On leaving King's College he served a pupilage at the works of Sir William Fairbairn in Manchester, where he remained three years.

His business life began in 1855, when he joined the firm of Courtney, Stephens and Company, of the Blackhall Place Ironworks, Dublin. There he did a great deal of general engineering

[1] Minutes of Proceedings Inst. C.E., vol. lv. p. 418; vol. lx. p. 220; vol. lxxxiv. p. 151.

work, including many appliances for railway signalling. He designed several cranes at that time, and Stoney, in his "Theory of Strains in Girders and Similar Structures," refers to the fact that Mr. Anderson was the first to adopt the braced web in bent cranes.[1] To this period of his life belongs his marriage. On the 11th November, 1856, he married Miss Emma Eliza Brown, daughter of the late Rev. I. H. Brown, Incumbent of Knighton, Radnorshire, the ceremony taking place in Knighton Church. In 1863 he became President of the Institution of Civil Engineers of Ireland, to which Society he contributed several Papers.[2] During his stay in Dublin he met with a severe accident at Messrs. Manders' Brewery, where he was looking after some work. In some way his right arm was caught between two toothed wheels, which he had already pointed out were dangerous, and the elbow was much damaged. Most of the doctors who were called in said that amputation was inevitable, but his family doctor considered that the arm could be saved. Mr. Anderson decided to act on the latter opinion, the result being that, having a splendid constitution, his arm was restored almost to its normal condition, the only effect being that he was not again able to raise the right hand above the level of his chin. In some things, therefore, he became left-handed, such as in drinking out of a cup or tumbler.

In 1864 Mr. Anderson joined the old established firm of Easton and Amos, of the Grove, Southwark, S.E., and at once went to live at Erith, where the firm had decided their new works should be erected. The design and laying out of these devolved mainly on Mr. Anderson, and although the changes in the class and character of the work carried out since that time have suggested improvements, they undoubtedly were then, and even are now, a model of what such works should be. The particular business at that time was pumping machinery of all kinds, centrifugal pumps, cranes, boilers, and paper and sugar machinery. Mr. Anderson gave much attention to centrifugal pumps, and materially improved the pattern adopted by Mr. Appold. In 1870 the firm took a large contract for three sugar mills for the late Khedive Ismail of Egypt, the greater part of the designing of which fell to Mr. Anderson's share. He spent a considerable time in Egypt during the erection and starting of the mills, and in 1872 presented to the Institution

[1] Page 133.

[2] Transactions of the Institution of Civil Engineers of Ireland, vol. v. pp. 116, 183; vol. vi. pp. 187, 188; vol. viii. pp. 38, 173; vol. ix. p. 78.

an account of the factory at Aba-el-Wakf,[1] for which he was awarded a Watt medal and a Telford premium.

He next turned his attention to gun mountings of the Moncrieff type, and designed several for the British Government, which were made at the Erith works. In 1876 he designed a pair of twin Moncrieff turret mountings for 40-ton guns for the Russian Admiralty, which were in due course made at Erith and proved highly successful. Later he designed some similar mountings for 50-ton guns, also for Russia, one pair of which was made at Erith, two other pairs being made in Russia to the same design. Finally he designed the mountings for H.M.S. "Rupert" shortly before he was appointed to Woolwich. He also designed a high-angle fire mortar mounting for the American Government, which answered very well, and many were made to the design in the United States, bringing in for some years a considerable royalty to the firm for the patent, which, it should be added, was taken out jointly with Colonel Razkazoff, of the Russian Government, with whom Mr. Anderson had been associated for many years in the employment of disk springs for gun mountings.

About the years 1878–82 he was much occupied with two large contracts the firm had obtained for the waterworks of the towns of Antwerp and Seville. In the former he was confronted with the problem of making the only available water, that of the River Nethe, which was little better than a sewer, fit for drinking purposes. It was solved by the use of spongy iron in the filters, an application of an invention by Mr. Bischof. This was only partially successful, however, and his mind soon had to return to the subject. The result was the invention, in conjunction with Sir Frederick Abel, of the revolving iron purifier, which was at once adopted and has been in use since. He presented to the Institution a description of the Antwerp works and of this iron process,[2] for which he was awarded a Telford medal and premium. In several other places this process has been adopted with success, and within the last few years has been installed on a large scale at the waterworks of Paris. Strange to say, however, it has made no headway in England.

One of the last works Mr. Anderson was engaged on before receiving the Woolwich appointment was the machinery for the two great lifts of the Chignecto Ship Railway. These were fully designed, and the work was mostly sent out to the site and was

[1] Minutes of Proceedings Inst. C.E., vol. xxxv. p. 37.

[2] *Ibid*, vol. lxxii. p. 24.

partly erected, when the failure of the contractor put an end to the enterprise.

Shortly before his appointment he was asked by the Explosives Committee of the War Office (Sir F. Abel, Professor Dewar and Dr. Duprè) to design the machinery for the manufacture of the new smokeless explosive "cordite." He, however, had barely started upon this when, in 1889, he was offered and accepted the post of Director General of the Ordnance Factories, and the duties of that post precluded him from continuing to act in connection with the cordite machinery, which work was handed over to his eldest son, who had assisted him in what he had already done. This appointment involved complete severance with his old firm, so much so that, even though he was able to continue his residence at Erith, he scarcely entered the Erith works again, though he was always ready to give advice about any of the old work.

Of his work at Woolwich Arsenal it is not possible to write in detail. The position was one which demanded the exercise of great tact and experience, and no one could have been found more gifted in those qualities than Mr. Anderson. He made many improvements in the details of management of the Arsenal, thereby removing numerous sources of waste of money, which his experienced eye quickly detected, and there is no doubt that at the time of his death the factories were working far more economically than when he took up the post. It may be pointed out that besides the Arsenal at Woolwich, his office gave him the control of the Enfield and Sparkbrook Small Arms Factories, and the Gunpowder and Cordite Factory at Waltham Abbey.

Mr. Anderson was elected a Member of the Institution on the 12th January, 1869. In 1886 he was elected a Member of Council, and in 1896 a Vice-President. He was also a Member of the Institution of Mechanical Engineers, of which he was President in 1892 and 1893. In 1891 he was elected a fellow of the Royal Society. In 1889 he was President of Section G of the British Association Meeting at Newcastle, and on that occasion the degree of D.C.L., *honoris causâ*, was conferred upon him by the University of Durham. He was a Vice-President of the Society of Arts, and a Member of the Royal Institution, of the Iron and Steel Institute, and of other societies. He was also a Lieutenant-Colonel of the Engineer and Railway Volunteer Staff Corps. In 1895 her Majesty was pleased to confer the honour of C.B. upon him, and in 1897 that of K.C.B.

Sir William Anderson contributed many Papers to scientific societies. In addition to those already referred to he presented

the following to this Institution:—"A Visit to Some Peat Works in the Neighbourhood of St. Petersburgh,"[1] "The Emission of Heat by Hot-Water Pipes,"[2] "Notes of a Journey through the N.E. Portion of the Delta of the Nile in April, 1884."[3] In 1883 he delivered the second of the series of lectures on Heat in its Mechanical Applications, his subject being "The Generation of Steam, and the Thermo-Dynamic Problems Involved;" and in 1893 he gave the first "James Forrest" lecture, his theme being "The Interdependence of Abstract Science and Engineering."[4] Among the information contributed by him to other societies may be mentioned his address as President of the Institution of Mechanical Engineers in 1892,[5] "The Development of Graphic Methods in Mechanical Science,"[6] "The Action of Waves and Currents in Estuaries,"[7] "Revolving Purifier for the Treatment of Water by Metallic Iron,"[8] and "The Mechanical Properties of Cork."[9] His Howard lectures on the "Conversion of Heat into Useful Work,"[10] delivered before the Society of Arts in 1884–85, have since been republished, and now form a recognised text-book on that subject. In 1878 he delivered a series of seven lectures on hydraulic machinery at the School of Military Engineering, Chatham.[11]

For several years he was examiner in engineering at the Royal Indian Engineering College, Cooper's Hill, and instituted the system of setting papers for the students to do at home or in their rooms, allowing free access to all books and notes, only placing them upon their honour not to ask anyone to help them. He maintained that this was a far better way of determining the real worth of a man than the usual method. For many years he took great interest in the trials conducted by the Royal Agricultural Society, of which he was a consulting engineer. On giving up that post he was made a member of the Implement Committee, and acted as a judge of the trials on more than one occasion.

No biographical sketch can be considered complete without some reference to his life outside his professional duties. He

[1] Minutes of Proceedings Inst. C.E., vol. xli. p. 202.
[2] *Ibid*, vol. xlviii. p. 257.
[3] *Ibid*, vol. lxxvi. p. 346.
[4] *Ibid*, vol. cxiv. p. 255.
[5] Proceedings Institution of Mechanical Engineers, 1892, p. 106.
[6] Report of the British Association, 1889, p. 322.
[7] *Ibid*, 1890, p. 512.
[8] *Ibid*, 1891, p. 762.
[9] Proceedings of the Royal Institution, vol. xi. p. 436.
[10] Journal of the Society of Arts, vol. xxxiii. pp. 543, 557, 573, 643, 724, 804.
[11] These lectures are in the Library of the Institution.

was a true Christian, filled with the importance of the duty of doing good to his fellow-men in every possible way, and the town of Erith, in which he lived for thirty-four years, has every reason to be grateful to him. He was the first chairman of the Local Board on its formation, and held the office for some years. For many years he was a magistrate, and attended petty sessions regularly until his Woolwich appointment rendered it impossible for him to continue to act. But his chief work was the education of children. After the passing of the Education Act of 1870 the School Board of Erith was at once formed, and he was one of the original members, retaining his seat until obliged to resign early in 1898 on account of ill-health. His interest in children did not, however, stop there. Not content with looking after them on week-days, he acted for twenty-five years as superintendent of the Sunday-schools of Christ Church, Erith, and spent a great part of his Sunday in teaching or working in connection with those schools, learning to know nearly every child in the place. It is touching to note how this Sunday work was uppermost in his mind, for it is recorded that within an hour or two of his death he was heard to be muttering something half unconsciously. One of his sons listened attentively, and made out that it was an address to the Sunday-school children such as he had been in the habit of giving nearly every Sunday for twenty-five years. He took an active part in building Christ Church, Erith, and the schools attached to it. He was, however, no bigoted churchman, but would always assist other denominations in every possible way. He was a licensed Lay Reader, and in past years frequently conducted the services at a mission chapel in connection with Christ Church.

His chief recreation was his workshop. He was an admirable workman both in wood and metal, a gift inherited from his father, and his work was always thoroughly good everywhere alike. Inside parts which would never be seen again were finished with the same care and accuracy as the most prominent portion.

For about a year before his death Sir William Anderson suffered from heart trouble, and had to forego all physical exertion. He therefore left his house at Erith and took up his residence at the Arsenal. He spent some time in the spring and summer at the seaside, and in the autumn took a house at Blackheath, where his health improved so much that in November he returned to the Arsenal. A reaction, however, set in again very shortly, dropsical symptoms returned, and the shock of an operation performed on Saturday, the 10th December, 1898, caused his death

on the following day. He had not lost touch with his work all through his illness, and was able to some extent to attend to it as late as the 9th December.

His character was a beautiful one. He was filled with love for all things, and everyone who really knew him loved him also. He had no lust for money; he worked for work's sake, and because it was a sacred duty, rather than for gain, and he freely spent that which he had for the good of others, and but little on himself. He always had a perfectly serene and calm mind. No one ever saw him angry or heard a hasty or unkind word proceed from his lips. Those in difficulty or trouble naturally came to him, assured in advance of help or advice, and no genuine case of distress was disappointed.

FREDERICK ASHMEAD, born in Bristol on the 4th May, 1825, was the second son of the late Mr. G. C. Ashmead, land agent and surveyor, of that city. He was educated in Bristol, and, after serving articles to Mr. Underwood, a local architect, joined the engineering staff of the South Wales Railway, now part of the Great Western Railway system. He was first stationed at Newport, and was subsequently appointed Resident Engineer on the construction of the Bridgend and Neath section of the line.

About the year 1851 Mr. Ashmead returned to Bristol, and became an assistant to the late Mr. Armstrong, the then City Surveyor. On the death of that gentleman in 1854, Mr. Ashmead was appointed Surveyor to the Local Board of Health, and when that body was merged in the Sanitary Authority he was appointed Borough Engineer. During his term of office, which extended over forty years, Mr. Ashmead designed and carried out a new system of drainage for the city, laying intercepting sewers to take the drainage, which formerly emptied itself into the Rivers Avon and Frome, and to carry it ultimately to the Bristol Channel. In 1875, at the Bristol meeting of the British Association, he read an interesting Paper on the drainage of the city.[1] In 1894 Mr. Ashmead retired from the post of Borough Engineer, his services being retained, however, as Consulting Engineer in connection with the important question of the sewage disposal of the city, still under consideration.

Mr. Ashmead died at Upper Belgrave Road, Durdham Down, on

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[1] Report of the British Association, vol. xlv. p. 240.

the 23rd August, 1898, only ten days after the death of his wife, to whom he had been married nearly fifty years. He was a sound and able engineer, gifted with considerable foresight, and the city of Bristol is in no small degree indebted to him for the way in which he carried out the duties of his office. Mr. Ashmead was President of the Incorporated Association of Municipal Engineers in 1877. In manner he was retiring and modest, courteous and straightforward, and he gained the respect of those who sometimes differed from him in opinion.

Mr. Ashmead was elected a Member of the Institution on the 4th April, 1865.

WILLIAM BELK, son of the late Mr. Thomas Belk, Recorder of Hartlepool, was born on the 6th February, 1849. After being educated at the Royal Grammar School, Lancaster, he served an apprenticeship of five years to Messrs. Thomas Richardson & Sons, mechanical engineers, of Hartlepool. He was subsequently employed by that firm in their marine-engine department, and in erecting machinery abroad.

In October, 1874, Mr. Belk was appointed assistant to Mr. John Howkins, then Engineer to the Hartlepool Port and Harbour Commissioners, and on the resignation of that gentleman in July, 1877, he succeeded to the post, which he held until his death. Among the works which Mr. Belk carried out as Engineer to the Commissioners may be mentioned the construction of a breakwater at the Heugh, the deepening by means of dredging of the approach to the harbour and docks, the improvement of the lighthouse, and the erection of sea-walls and groins. Mr. Belk died on the 16th July, 1898, at the comparatively early age of 49. He was elected a Member on the 9th January, 1883.

FRANCISCO JAVIER CISNEROS was born on the 28th December, 1836, at Santiago de Cuba. After having passed through the School of Engineering in Havana, he obtained employment on the Cuban railways. In 1857–58 he was engaged on the construction of the Sagua la Grande Railway; at the end of the latter year he took charge of a branch of the Matanzas Railway; and in 1859 he added to that work the charge of the Trinidad and Sancti Spiritu Railway which he retained until

1862. He was then for 6 years connected with the Eastern Railway of Cuba, and in 1868 he acted as Chief Engineer of the Caibarien Railway. The latter post he was obliged to resign at the end of that year, as he had to leave Havana, having been implicated in the insurrection of the Cubans against the Spanish Government.

In 1872 Mr. Cisneros became an American citizen, and was for a time in partnership in New York with Mr. A. G. Menocal. In the following year he went to the United States of Colombia, where he at once engaged in railway work. The Antioquia Railway from Puerto-Berrio on the Magdalena River to Paras, the Cauca Railway, the Girardot Railway from Girardot to Juntas de Apulo, and the La Dorada Railway connecting the Upper and the Lower Magdalena, were constructed by Mr. Cisneros. He also organised an enterprise of steamboats on the Magdalena River and regulated the mail service between the sea-ports and the interior of the country. In 1893 a pier at Barranquilla, over 4,000 feet long, which had been carried out under his direction, was opened for the service of the railway and steamers.

Mr. Cisneros was a strong advocate of the policy of the annexation of Cuba to the United States, and he contributed largely from his means to the support of the insurrection in that island which led to the recent war between Spain and the United States. He was a man of great intelligence and resource, and was distinguished by innate courtesy, tact and generosity. Mr. Cisneros died at New York on the 7th July, 1898, in his sixty-second year. Several of his reports may be found in the Library of the Institution, of which he was elected a Member on the 5th February, 1884.

Sir JOHN FOWLER, Bart., K.C.M.G., LL.D.,[1] who died at Bournemouth on the 20th November, 1898, at the age of eighty-one, was one of the most eminent of the engineers whose names are associated with the great material progress effected during the Victorian era. By his death is snapped one of the few remaining links which connect the present generation to the Railway Mania and to the stirring times which preceded it. It

[1] This Notice is, with some additions relative to Sir John Fowler's association with the Institution, reprinted, by permission of the Editors, from *Engineering* of the 25th November, 1898.

may be truly said "There were giants in those days," men not only of immense intellect and of great force of character, but also endowed with the physical strength to carry them unharmed through arduous days and toil-laden nights to live far beyond the allotted span. The opening of the Manchester and Liverpool Railway in 1830 was the commencement of an epoch rich in opportunities, and equally rich in men capable of turning them to full advantage. A new department of engineering had to be created without aid from precedent, and it rapidly attained such magnitude that it provided abundant work for all who had the necessary talent. Among these none was more conspicuous than Sir John (then Mr.) Fowler. He immediately attained a commanding position, which he kept until the close of his life. An independent professional career, commencing before the Railway Mania, and extending some years beyond the completion of the Forth Bridge, is indeed a notable record, and it is scarcely possible that one quite like it will ever occur again. It lifts its author out of the ordinary category of engineers, and puts him among the few who have written their names in broad characters across the face of the nineteenth century. During the whole of the period he was in the forefront of the struggle in subduing the great powers of Nature to the service of man, and wherever the difficulties were greatest he was certain to be found.

The salient feature in the character of Mr. Fowler was his intense self-reliance. When he had made up his mind that a course of conduct was practicable and desirable, he never felt any misgivings, but went straight on with it in spite of all difficulties. He was not content to take his opinions from others, or to act upon views with which he was not in complete harmony. He held that the whole duties of an engineer were not comprised in the mere accomplishment of the objects entertained by his employers. It was his duty, he considered, to advise those who consulted him whether the undertaking was one that would repay the expenditure that must be made upon it. The engineer was not merely a man of technical skill engaged to bridge the difficulties of capitalists, as a servant carries out the orders of his master. On the contrary, he was a member of an honourable and noble profession which could not lend itself to enterprises that did not give fair promise of being beneficent to the world and to the advancement of civilization. A notable example of the influence exerted by Mr. Fowler, and the confidence he was able to inspire in others, was afforded during the construction of the Metropolitan Railway. The first enthusiastic anticipations of its

success were soon followed in the public mind by a doubt as to the possibility of its being constructed. The directors were constantly being told that they had embarked their money and that of the shareholders in an impossible enterprise. Engineers of eminence assured them that they could never make the railway, that if they made they could not work it, and if they worked it nobody would travel by it. Such a catalogue of impossibilities was enough to appal anyone, and often faith in the enterprise fell to a low ebb. At such times the directors would say to Mr. Fowler, "We depend on you, and as long as you tell us you have confidence we shall go on." It was a heavy load to put on the shoulders of a man who had already sufficient to attend to in combating the physical difficulties of the affair. Yet Mr. Fowler never flinched. He had made up his mind that the railway could be constructed and that it would answer its purpose.

Mr. Fowler's self-reliance showed itself in the courage with which he tackled schemes of magnitude far beyond anything previously attempted. His mental gait was not that of the toddling child who fears to relinquish its hold on one object before it can grasp a second. Rather was it that of the athlete who will launch himself across a chasm, certain that his eye can measure the distance, and that his muscles will respond instantly and accurately to the command of his brain. Strong in his experience and in his grasp on principles, and confident in his mechanical instinct, he would put his professional reputation to the hazard in a way that men of equal skill, but wanting his courage, would have failed to do. The Forth Bridge affords a case in point. It was not only far larger than any railway bridge previously built, but it was of a very novel design. It was commenced with the full consciousness that its execution bristled with unknown difficulties, which would have to be met and conquered as they made themselves evident. Yet Sir John Fowler was satisfied that the project was feasible, and he did not doubt that he and his colleagues would be quite able to accomplish it. In this instance he was fortunate in having clients who had a perfect belief in his powers, and who could command the required capital. Many of Mr. Fowler's enterprises were too bold for the British investor, and could not be attempted for want of funds. He could convince the men with whom he came in personal contact, but, of course, the great body of the public was beyond his reach.

Mr. Fowler was born on the 15th July, 1817, at Wadsley Hall, Sheffield, the residence of his father, who also was called John Fowler. He received a good general education, and at the age of

seventeen became a pupil of Mr. J. T. Leather, the well-known hydraulic engineer, under whom he saw a good deal of practice, particularly in the water-supply of large towns. At that time the construction of railways in this country had fairly commenced. The Stockton and Darlington line was opened when Mr. Fowler was eight years of age, and the Manchester and Liverpool line when he was only thirteen. It was natural, therefore, that on leaving Mr. Leather's office, Mr. Fowler should turn to railway work. He entered the employment of Mr. J. U. Rastrick, where he was principally engaged on the design and superintendence of the railway from London to Brighton. After two years he returned to Mr. Leather, and became the responsible resident engineer for the Stockton and Hartlepool Railway. After it was completed he remained two years as engineer, general manager, and locomotive superintendent of that and the Clarence Railway. On the termination of this engagement Mr. Fowler visited, at the invitation of Sir John Macneill, several railways in the neighbourhood of Glasgow, and gave evidence before Parliamentary Committees respecting them. He was twenty-six years of age when he thus started an independent career. Several important railways were then being promoted from Sheffield, such as the Sheffield and Lincolnshire, the Great Grimsby, the New Holland, the East Lincolnshire, and others, and of these Mr. Fowler became the chief engineer, conducting them through Parliament, and carrying them out. It was in 1843 this work was commenced, and before it was completed, the Railway Mania attained its full proportions. How wild it was, a single incident in Mr. Fowler's career will show. One night when asleep in his father's house, a carriage and four drove up to the door, and the household was aroused by loud knocking. On descending, Mr. Fowler found that a prominent director of railways had called with the purpose of inducing him to undertake the engineering of a new railway from Leeds to Glasgow, and that he had brought £20,000 as a preliminary payment on account of survey expenses. It then only wanted a few weeks before the day for depositing the plans, and Mr. Fowler declined the offer, leaving the promotor to go away disappointed.

Mr. Fowler was in the thick of these stirring times, and took part in many a well-fought battle before Parliamentary Committees. Among the works about which he was consulted, or which he carried out at that and later times, may be mentioned the Oxford, Worcester, and Wolverhampton Railways; the Severn Valley Railway; the London, Tilbury, and Southend Railway (in connection with Mr. Bidder); the Liverpool Central Station;

the Northern and Western Railway of Ireland; railways in New South Wales and in India; the Sheffield and the Glasgow Water Works; the Metropolitan Inner Circle Railway; the St. John's Wood Railway; the Hammersmith Railway; the Highgate and Midland Railway; the Victoria Bridge and Pimlico Railway [1]; the Glasgow Union and City Railway; St. Enoch's Station, Glasgow; the Millwall Docks; the proposed Channel Ferry; and many others.

Mr. Fowler's reputation with the general public of this generation rests, to a great degree, on his constructon of the Metropolitan Railways.[2] These were so far out of the common that every Londoner, and many people out of London, took the greatest interest in them. It was in 1853 that the first Act was obtained for a line of 2¼ miles in length, from Edgware road to Battle Bridge, King's Cross. Plans for extension westward to Paddington, and eastward to the City, were at once prepared, and the financial support of the Great Western Railway Company was secured. After a severe fight the Act for the extended railway was obtained, the plans providing for tunnels and stations large enough to accommodate the broad-gauge Great Western trains, as well as narrow-gauge local trains. There was, however, a difficulty in raising the capital, and it was not till the spring of 1860 that the contract was made and the works commenced. In 1861 powers were obtained for extending the Metropolitan Railway to Moorgate Street, and in 1864 for constructing the eastern and western extensions to Tower Hill and Brompton respectively. In 1863 a Lords Committee decided that it would be desirable to complete an inner circuit of railway that should abut upon, if it did not actually join, nearly all the principal termini in the Metropolis, commencing with the extension in an easterly and southerly direction from Finsbury Circus at the one end, and in a westerly and southerly direction from Paddington at the other, and connecting the extremities by a line on the north side of the Thames. This railway will ever remain a monument to the skill of the engineers engaged on its construction. Of these Mr. Fowler was responsible for the greater part.

The main lines of the Metropolitan and Metropolitan District Railways being complete, Mr. Fowler carried out the railways in connection with them, including the St. John's Wood Railway, the Hammersmith line, the West Brompton line, and others. His

[1] Minutes of Proceedings Inst. C.E., vol. xxvii. p. 55.
[2] *Ibid*, vol. lxxxi. p. 1.

original plan, brought before the Parliamentary Committee, included an outer circle as well as an inner circle, but unfortunately the former was rejected.

In 1870 Mr. Fowler was one of a Commission sent to Norway to investigate the subject of light railways, with a view to their adoption in India. The majority decided in favour of a 2-foot 9-inch gauge, while Mr. Fowler presented a minority report, recommending 3 feet 6 inches. Ultimately the Government adopted the metre gauge, thus leaning to the views of Mr. Fowler rather than of his colleagues. In 1868 the subject of this memoir went to Egypt for his health, and there was then commenced a professional connection with that country which lasted for eight years; as long, in fact, as Ismail Pacha sat on the throne. That ruler had force of character without judgment, and loved big schemes, unmindful of the fact that the basis of prosperity lies not in science but in good government. He employed Mr. Fowler to design irrigation plans on an enormous scale, to project a waterway across the Isthmus in competition with the Suez Canal, and to survey a railway to Khartoum. Had this latter been completed it would have greatly modified Egyptian history. Many of Mr. Fowler's smaller plans were successfully carried out, but the larger ones were mostly stopped by the breakdown of Egyptian credit, and the subsequent military revolt. When the British took control of the country, Mr. Fowler put his great knowledge of its characteristics at the disposal of the Government, and this service was acknowledged by his being made a Knight Commander of St. Michael and St. George, in 1885.

The next great work in Mr. Fowler's career was the Forth Bridge. When the Tay Bridge was destroyed, preparations were being made, and were actually commenced, for bridging the Forth. Sir Thomas Bouch had designed a suspension bridge for the purpose, and an Act of Parliament had been obtained authorising its construction. The failure at the Tay at once threw doubts upon the safety of this most ambitious project, and the works were stopped. Subsequent investigations showed that the proposed bridge could not have been satisfactory. On the 18th February, 1881, the four great railway companies concerned, the Great Northern, the North British, the Midland, and the North-Eastern, wrote to their consulting engineers—Mr. T. E. Harrison, Mr. W. H. Barlow, and Mr. Fowler, associated with Mr. (now Sir) Benjamin Baker—propounding two questions for their joint opinions. They were asked to consider the feasibilty of building a bridge for railway purposes across the Forth, and, assuming the

feasibility to be proved, what description of bridge it would be most desirable to adopt? The matter involved so large an expenditure, and contained so many novel issues, that it needed to be approached with the greatest possible care. Calculations of the weight and cost of different types of bridge were made and discussed by the four engineers, with the general result that the cantilever type was chosen. A report was made to the railway companies on the 4th May, 1881, embodying the result of the deliberations, and pointing out that the cantilever principle offered a better and cheaper solution of the problem than any other. The report did not enter into the details of construction; indeed, it could not be said to give even the broad features, other than those which are involved in the use of the cantilever. These still remained to be elaborated in council, and it was only by united discussion that the original plan developed into the final design. After most elaborate investigations and calculations, the structure gradually, by a process of evolution or development, assumed its present form. The design being settled and the execution decided upon by the associated railway companies, the carrying out of the work was entrusted to Mr. Fowler, in conjunction with his partner, Mr. Baker. The parliamentary contest was very fierce, as there were powerful interests opposed to the erection of the bridge, but its authors were victorious and the Bill was passed.

It is not proposed to trace the building of the Forth Bridge. The matter is so recent that it is common knowledge, and those who wish to follow it closely will find a full account in *Engineering* of the 28th February, 1890.[1] In this they will also find a detailed history of the career of Sir John Fowler up to that date, written from material supplied by himself and corrected by his hand. It is sufficient to say that the bridge was opened by the Prince of Wales on the 4th March, 1890, when the Queen was graciously pleased to confer a baronetcy on Sir John Fowler, and to make Mr. Baker a Knight Commander of St. Michael and St. George.

At 73 years of age, Sir John could fairly claim the right to slacken his exertions, and to enjoy some degree of rest, although he never actually retired from the exercise of the profession, and until illness laid him aside he was consulted on numberless projects. A simple recital of all the great schemes with which he was connected would occupy considerable space, while his life, if

[1] A brief account of the Forth Bridge appeared in the Minutes of Proceedings Inst. C.E., vol. cxxi. p. 309.

it should be written *in extenso*, would touch upon many of the engineering achievements since 1843. Only a few disjointed episodes have been referred to, rather to give a clue to the character of the man than to trace the steps of his professional career. He was so broad in his knowledge, so many-sided in his attainments, that he stands out in bold relief among the many remarkable men who were the product of the age which gave him birth. The present time is different, and it is not likely engineers will ever again have the remarkable opportunities that fell to the lot of the past generation. Specialization, with all its advantages from the clients' point of view, does not foster that all-round ability and catholic comprehensiveness which distinguished the engineers of the early Victorian period. This generation must be content to keep near to one track, but it need not on that account miss the lesson to be learned from such lives.

Sir John Fowler was an ardent sportsman, and was fond of deer-stalking in his extensive Scotch forests. He was also fond of yachting. His Scotch seat was Braemore, in Ross-shire, for which county, as also for Inverness, he was J.P. and D.L. In 1850 Sir John Fowler married Elizabeth, daughter of Mr. James Broadbent, of Manchester, and he is succeeded in the baronetcy by his son, Mr. John Arthur Fowler, born in 1854.

Sir John Fowler's connection with the Institution extended over more than fifty-four years, he having been elected a Member on the 6th February, 1844. He became a member of Council in 1849 and a Vice-President in 1859, and on the 19th December, 1865, he was elected President, which office he served for two years. On the 9th January, 1866, he delivered an inaugural address,[1] which was so important and valuable that it has been reprinted and distributed extensively, notably by the Government of India, to the engineers in its employment. It dealt with the subject of the education of an engineer at a time when the matter had not received so much attention as it has since, and showed that the Author was no blind admirer of the rule-of-thumb days during which he started his own career. A few lines may serve to show the fine ideal Sir John Fowler had of the scope of engineering. He supposed a boy to start at fourteen years of age, after a good liberal education. The next four years he devoted to mathematics, natural philosophy, surveying, drawing, chemistry, mineralogy, geology, strength of materials, mechanical motions, and the principles of hydraulics. To these were to be added French and German, even

[1] Minutes of Proceedings Inst. C.E., vol. xxv. p. 203.

at the expense of classics and pure mathematics. Then followed four or five years in an office or a workshop, supplemented by continued study in the above subjects. When it is remembered that this was nearly thirty-three years ago, it will be seen that appreciation of technical education is by no means a modern feeling, and that some whom an irreverent generation is apt to term "fossils," had quite as clear a perception of its value as the latest professor-bred youth.

An important outcome of this address was a memorial to the President and Council, signed by nearly one hundred engineering pupils and assistants, suggesting "the establishment, under the auspices of the Institution, of what might be called a 'Junior Engineering Society,' to consist of pupils and past pupils of civil and mechanical engineers, with the avowed purpose of mutual self-improvement in professional knowledge, and more particularly in that scientific knowledge of theory, which is becoming more and more essential to the success of the young engineer."[1] In the result the Council decided to recommend the extinction of the old Graduate class, and the creation, in its place, of the present class of Students. This recommendation was adopted by a general meeting of the Members held on the 26th June, 1867.[2]

During the Presidency of Sir John Fowler the question of rebuilding the premises in Great George Street received serious consideration. The purchase of Nos. 15 and 16 Great George Street, and the erection on that site of an entirely new building were recommended. Sir John Fowler took great interest in the matter and promised £2,000 to the fund proposed to be raised among the members to defray the cost of that scheme. It was decided, however, at the Special General Meetings held in June, 1866, for the purpose of receiving the report upon the building question, that the consideration of the subject should be not further proceeded with, and that the subscription list—which then amounted to about £25,000—should be withdrawn and cancelled.[3]

On the establishment of the Benevolent Fund in 1864, Sir John Fowler contributed largely towards its foundation, and continued to give support to it until the time of his death. He also acted from 1867 as a Trustee for the Capital Account of the Fund.

In concluding this Notice it may be said that during the whole

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[1] Minutes of Proceedings Inst. C.E., vol. xxvi. p. 123.
[2] *Ibid*, vol. xxvii. p. 125.
[3] *Ibid*, vol. lxxxvi. p. 160.

period of his long connection with the Institution, Sir John Fowler displayed the greatest activity in promoting its welfare, and that his services have proved of marked value in establishing its position and advancing its interests.

SIR CASIMIR STANISLAUS GZOWSKI, K.C.M.G., Honorary A.D.C. to the Queen, died at Toronto on the 24th August, 1898, at the age of 85. Born at St. Petersburg on the 5th March, 1813, he was a son of Stanislaus, Count Gzowski, who held a commission in the Russian National Guard and was descended from an old Polish family, ennobled in the sixteeenth century. The subject of this notice was educated at the Military Engineering School at Kremenetz, and in 1830 obtained a commission in the Imperial Russian Engineers. Three years later, however, owing to the part he, with other officers of the same nationality, had taken in the Polish insurrection of 1830–31, he was, after having been confined in a military prison for some months, shipped to the United States. With his fellow-exiles, he landed in New York in the summer of 1833, without friends or money, and with nothing but his engineering skill and an iron constitution to aid him.

Gzowski's first task was to learn the English language, of which he was entirely ignorant. While thus occupied, he obtained the means of livelihood by teaching German and French in New York, and by giving lessons in drawing and fencing. Turning his attention to law, he articled himself to Mr. Parker Hall, of Pittsfield, Massachusetts, and while studying under that gentleman continued to maintain himself by teaching in his spare time. His industry, ability and social qualities, coupled with his romantic history, soon made him well known in Pittsfield. In 1837, he was admitted as a citizen of the United States, and was enrolled as an advocate in Pennsylvania, where he practised until 1841.

In the latter year, with a view of securing a contract in connection with the widening of the Welland Canal, Mr. Gzowski went to Toronto, where he met some of the leading public men of the Dominion. Sir Charles Bagot, who was then at the head of the Canadian Government, formed a high opinion of Mr. Gzowski's ability, and procured for him an appointment in the Public Works Department. This was the beginning of his long and distinguished career in the Dominion, extending over fifty-six years. In 1846 he became naturalized as a British subject. Two years later he left the Public Works Department, and was appointed Chief

Engineer on the construction of the St. Lawrence and Atlantic Railway, which subsequently formed part of the Grand Trunk system.

In 1852 Mr. Gzowski entered into partnership with Sir Alexander Galt, the late Mr. Luther H. Holton and the Hon. D. L. Macpherson. Among the works carried out by that firm were the railways from Toronto to Sarnia, Port Huron to Detroit, and London to St. Mary's in the province of Ontario, and the construction of the International Bridge across the Niagara River near Buffalo, which was completed in 1873. From that date Mr. Gzowski practised on his own account, and was largely consulted by the Dominion Government with reference to railways, canals and harbours. He was also interested in military matters, and took an active part in forming the Rifle Association of Ontario. He acted as President of the Dominion Rifle Association, and was instrumental in sending the first Canadian team to Wimbledon. In 1873 he was appointed Lieutenant-Colonel of the Central Division of Volunteers in Toronto, and six years later he was promoted to the rank of Colonel, and was gazetted an Honorary A.D.C. to the Queen. In recognition of valuable services rendered to the Dominion of Canada, he was created a Knight Commander of the Order of St. Michael and St. George in 1890. He held office in 1896 as Administrator of the Government of Ontario.

Sir Casimir Gzowski was Chairman of the Niagara Falls Park Commission, and was connected with several important financial undertakings. He was one of the founders of the Canadian Society of Civil Engineers, of which he was elected President for three consecutive years, 1889–91, and endowed a silver medal, known as the "Gzowski Medal," for the best original Paper read before the Society, besides contributing largely in other ways to its welfare. He married in 1839, Maria, daughter of Dr. Beebe, of Erie, Pennsylvania, an eminent American physician. Of his ability and energy some indication has been given in this Notice. As a man he was kind, courteous, and always ready to encourage and help the younger members of the profession.

He was elected a Member of the Institution on the 1st February, 1881.

JOHN HOPKINSON was born in Manchester on the 27th June, 1849. His father, who is still living and is a Member of this Institution, was a partner in a firm of manufacturing engineers. John was the eldest of five sons, all of whom attained to success

in their respective professions—a striking testimony to the excellence of their parental and early education. That there was a decided tendency in the family towards pursuits of a scientific character is shown by the fact that three of the brothers became engineers and one a Doctor of Medicine. The fifth, Alfred Hopkinson, who was second in order of age, took a different line, and is now Principal of Owens College, Manchester.

Mr. Charles Willmore, of Lindow Grove, and later of Queenwood, Hampshire, had charge of John's early education. Hopkinson used often to speak of the excellence of the training which he received at Mr. Willmore's hands. Bird-nesting in the New Forest, and other outdoor pursuits, formed a large part of the school-life, and at this time, no doubt, was laid the foundation of that love of Nature in all her forms which was one of John Hopkinson's most pronounced characteristics.

In 1865 he went to Owens College. At that time Owens held an almost unique place among educational centres, in that it combined a good training in experimental science with studies of the more abstract character considered proper to the older Universities. The wide nature of the education which John received there is indicated by the fact that he was able in 1869 to gain a Whitworth Scholarship, coming out first in a competition which was intended more particularly for practical men who had undergone a training in the shops. In mathematics he was a pupil of Professor Barker. This gentleman recognized John's great power, and it was largely due to Barker that in 1867 he went in for, and obtained, a minor scholarship at Trinity College, Cambridge. As a further indication of the manner in which Hopkinson had been educated up to this time, it may be mentioned that in the following year he gained the Natural Science Exhibition at Trinity, as well as a Foundation Scholarship in Mathematics.

During his time at Cambridge Hopkinson regarded mathematical study as the chief end of his being, and worked hard under the able tuition of Dr. Routh. But though this took up the greater part of his time, it did not prevent him from sharing fully in all the other advantages, intellectual and physical, which life at the University afforded. He spent a fair amount of time on the river, rowing in the Second Trinity boat, of which he was captain; and a few weeks before his Tripos he won a college mile in remarkably good time, a feat of which he was justly proud. He was a member of the famous society known as the Apostles, which has numbered among its ranks most Cambridge men who have

attained to great eminence; and he read and thought much about logic and philosophy. His academic career was brilliantly successful. He was Senior Wrangler in the Mathematical Tripos of 1871—J. W. L. Glaisher being second—and he was subsequently first Smith's prizeman. During his time at Cambridge he obtained several distinctions at London University, becoming a Doctor of Science in 1871. He left Cambridge shortly after his Tripos, and was made a fellow of Trinity six months later.

Had engineering arrived in 1871 at its present stage of development, John Hopkinson's genius and education would have fitted him immediately to take a high place in the profession. In those days, however, a man who had not served in the shops found it somewhat difficult to obtain a good position. There were not many places in which a mathematical education would give him an advantage over his fellows with a more practical training. It was fortunate, therefore, that after about twelve months spent at his father's works, Hopkinson was offered the post of engineer and manager in the Lighthouse and Optical Department of the works of Messrs. Chance Brothers, of Birmingham. This was one of the few engineering positions in which his mathematical attainments could show to great advantage; they were indeed essential for much of the work he had to do. The designing of optical apparatus for lighthouses to suit the variable conditions as to distribution of light presented very considerable mathematical difficulties, and often required great ingenuity. Hopkinson designed many of the lights now in use all over the world, and superintended their manufacture at Chance Brothers'. Among them may be mentioned those at Macquarie and Tino, on which he contributed a Paper to the Institution in 1883.[1] In these electric light was used, and they were peculiarly successful. But it was not only in designing lenses that Hopkinson excelled when at Chance's. His originality and force of character told in every department which came under his influence. Piecework was introduced largely owing to his efforts, and resulted in greatly enhanced wages to the workmen and profits to the employers. He turned his attention successfully to the improvement of the mechanism for driving and supporting revolving lights. Perhaps, however, his most important invention at this period (1874) was that of the group-flash system. Great difficulty had been experienced in finding a satisfactory method of enabling the mariner readily to distinguish

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvii. p. 243.

one light from another. In one system the light was eclipsed at intervals, and one light differed from another in the length of the intervals between successive eclipses and in the duration of the eclipses. In practice it was found very difficult to distinguish lights so differentiated. The differences between the periods had to be very great to be perceptible, and this led to many objectionable features. In another system red glass was used to colour some of the flashes, thereby greatly obscuring the light. The use of this makeshift itself showed how difficult of solution the problem was. Hopkinson solved it by dividing each of the flashes in the older system into a group of two or three distinct "winks" in rapid succession. The groups occurred at stated intervals, and were separated by times of eclipse. The efficiency of the flash as a means of taking a bearing was little impaired by the short times of eclipse which divided it into a group. Different lights were distinguished by the number of "winks" in each group, and for the difficult observation of the duration of a flash was substituted the almost unconscious process of counting the number of subsidiary flashes into which it was divided. The group-flash system is now very largely used in lighthouses all over the globe. During this period Hopkinson also gave much thought to the practical application of electricity—an art which was then in its infancy. He did not, however, publish anything on this subject until later, though in the year 1877 he took part in a discussion at this Institution on the use of electric light in lighthouses.[1]

Thus his position at Chance's gave John Hopkinson a wide engineering experience, and at the same time it enabled him to employ to the full his mathematical and scientific powers for practical ends. In the latter respect his work in Birmingham was especially valuable and important for his development. In applying his optical formulas to the construction of real lenses he learnt what a powerful tool mathematics could be. He used to say that at first he felt a sort of pleased surprise when he found that his formulas came out right and that the lenses did in fact distribute the light as the mathematics indicated they would. This feeling, however, soon gave way to a confidence in new results obtained by deduction from laboratory and other experience and a correctness of judgment in the use of such deduction, which, perhaps more than any other quality of his mind, placed him in the front rank of the new school of engineers. But while he

[1] Minutes of Proceedings Inst. C.E., vol. lvii. pp. 135, 187.

learnt the power of mathematics in engineering, he at the same time became convinced that to be of any use it must be regarded simply as a tool—that the figures must conform to the facts, not the facts to the figures. The views on mathematics which he acquired at Birmingham were never changed; four years ago he expounded them in the "James Forrest" lecture, "The Relation of Mathematics to Engineering," delivered before this Institution.[1]

In the year 1873 appeared the first edition of Maxwell's "Electricity and Magnetism." Hopkinson read it with great care, and it produced a powerful impression upon him. At about the same time he made the acquaintance of Sir William Thomson (now Lord Kelvin). In a mind so active as his, two such influences were bound to start trains of scientific thought. In the course of the profession he had to study the properties of glass, and it was characteristic of him that his first scientific work of importance should also deal with that substance. Partly at the suggestion of Sir William Thomson, he made experiments in the years 1876 and 1877 on the residual charge of the Leyden Jar, and on the electrostatic capacity of glass. He published four Papers on these subjects in the Philosophical Transactions of the Royal Society.[2] He was a thorough convert to the electro-magnetic theory of light from the first, but his experiments on glass showed that there was a serious difference between the actual value of the capacity of that substance and the value deduced from Maxwell's theory from the refractive index. The investigation of the causes of this discrepancy in glass and other substances was the subject of a long train of research, which began with the work on residual charge above referred to, and culminated but two years before his death in experiments on "The Capacity and Residual Charge of Dielectrics as Affected by Temperature and Time." In a Paper[3] on that subject, he showed that electrolytic conduction, residual charge, and capacity, are but different names for one continuous phenomenon, namely, the effect produced on a dielectric by the passage of a current. That effect, however, is very greatly influenced by the time during which the electric current has been passing, and therein lies the explanation of the deviation from Maxwell's theory. Hot window glass was shown to behave as an electrolyte under long-continued application of electric force, whereas it exhibits the properties of a dielectric

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[1] Minutes of Proceedings Inst. C.E., vol. cxviii. p. 330.
[2] Philosophical Transactions of the Royal Society, 1876, 1877, 1878, 1880.
[3] *Ibid*, 1897.

without conductivity, if the duration of the current is short. As the time increases the capacity also appears to increase; the substance exhibits residual charge, and the change from one effect to the other is perfectly continuous. In the case of ice Hopkinson proved that the specific inductive capacity under an alternating electromotive force of a frequency of over a million per second is about 3, which is roughly what would be inferred from its refractive index; but as the frequency increases the apparent capacity also increases, simply by reason of residual charge, until at a frequency of 100 it is of the order of 80.

In 1878 John Hopkinson left Messrs. Chance Brothers and came to London, continuing, however, to be associated with that firm as Consulting Engineer. In the same year he was elected a Fellow of the Royal Society. He very soon obtained a considerable practice as an expert witness in patent cases, work for which his practical and scientific qualifications peculiarly fitted him. For ten years this constituted the most important, certainly the most lucrative, part of his professional work, and he attained a very high reputation as a scientific witness. Such work is of an evanescent character, but he did it with extraordinary ease and rapidity, and so was able to devote much time and energy to pursuits of more lasting value. Indeed the decade from 1880 to 1890 was, in original work, the most productive period of his life.

In the year 1881 electric lighting and electrical transmission of power were brought into considerable prominence by the Paris Exhibition. Hopkinson exhibited there an alternate-current dynamo of a new type and also a hoist, in which was embodied a practicable system of reversing the motor. At the same time he introduced and patented the series-parallel system of working motors, which has since been universally adopted in working tramcars and other motors, where a large starting effort and great range of speed are required. For the next few years he devoted all his inventive powers to the improvement of the appliances used for the generation and transmission of electricity. The theory of the dynamo machine was at that time in a chaotic state. The two Papers which Hopkinson read before the Institution of Mechanical Engineers[1] greatly helped to elucidate it. They described experiments which he had made with series-wound machines of the Siemens type, and introduced for the first time the use of the characteristic curve showing how, from that curve could be deduced the behaviour of the machine when put to work

[1] Proceedings Institution of Mechanical Engineers, 1879, 1880.

on various loads, such, for example, as an arc lamp or an ordinary resistance. During this period, too, he took out many patents on electrical subjects, that for the three-wire system of distributing electricity, in July, 1882, being the first to attain great practical importance. The system is now used in every large direct-current installation.

In 1883, in a lecture entitled "Some Points in Electric Lighting,"[1] delivered before this Institution, Hopkinson published his first important improvements in dynamo machines. It was not at that time understood what should be the proportions of the magnets and other parts of a dynamo-electric machine in order to obtain the greatest efficiency. Machines were constructed according to arbitrary rules and without regard to any rational principle. In the Edison machine, which was perhaps that most in vogue, the magnets were made very much too long, and of too small a section. Hopkinson, guided by that rational deduction from laboratory experiments of which he was so great a master, shortened the magnets, and increased their area of section, thereby greatly improving the efficiency of the machine and increasing the output from given weight of material.

The general solution of the problem underlying the construction of dynamo electric machines had, however, not yet been reached. John Hopkinson had indeed pointed out the principles which should guide manufacturers in order that they might obtain efficient machines, but it had yet to be shown that it could be predicted from the size and shape of the magnets and armature, and the number of windings, how any given machine would behave. The solution of this problem was made known in a joint Paper by the brothers John and Edward Hopkinson in 1886.[2] Six years before, Hopkinson had shown that from the characteristic curve of a machine a complete account of its properties could be obtained. The first point in the 1886 Paper was the construction of the characteristic curve from the dimensions of the machine. It was assumed as a first approximation that the magnets, armature, and air-space formed a closed magnetic circuit of a composite character, through every section of which the induction was the same. The characteristic curve was regarded as the expression of the relation between that induction and the line-integral of magnetic force round the circuit,

[1] The Inst. C.E. series of Lectures on "The Practical Applications of Electricity."

[2] Philosophical Transactions of the Royal Society, 1886.

and it was built up, so to speak, from the known magnetic properties and dimensions of the various parts of the circuit. In the second half of the Paper, experiments on a dynamo were described in which the theory in its general character was verified, and the causes of discrepancy, such as waste field and armature reaction, were thoroughly investigated. This Paper was perhaps the most important of Hopkinson's publications from the point of view of practical engineering. It put into the hands of dynamo designers a means of constructing in the drawing office machines of any given output; the method is of universal application, and is now always used in the manufacture of dynamos.

In 1890 Hopkinson was appointed Honorary Professor of the Electrical Engineering Laboratory at King's College, London, which was founded by Lady Siemens, in memory of Sir William Siemens. This gave him great facilities for experiments and he carried his researches in dynamos much further. In these he was efficiently helped by Mr. Ernest Wilson, who has succeeded him as Professor. The first work done at King's was a detailed inquiry into the effects of armature reaction, the theory of which had been stated, but only partially verified in the 1886 Papers. Then followed researches on alternate currents. Hopkinson had already made important communications on this subject. In a Paper read before the Society of Telegraph Engineers in 1884 he had discussed the theory of alternating current dynamos, and a fuller communication of the same character was published in the Proceedings of the Royal Society in 1887. The experiments at King's College were undertaken with a view to verifying the theory developed in these Papers. The current and electromotive force at various epochs in an alternate-current dynamo, when working on various loads, were determined by means of a revolving contact-maker. The results were published in 1896 in the names of John Hopkinson and Ernest Wilson.[1] The point of greatest practical interest in the Paper was the determination of the effect of Foucault currents in the magnet cores, the importance of which had not till then been appreciated. Important experiments on transformers were also carried out at King's. Here, again, Hopkinson had done much work on the subject at an earlier date. As early as 1884 he patented the closed-circuit transformer, and in 1887[2] he published a theory of that instrument based on the actual properties of the

[1] Philosophical Transactions of the Royal Society, 1896.
[2] Proceedings of the Royal Society, 1887, p. 164.

iron.[1] Of the experiments at King's perhaps the tests which he made on two of the Westinghouse Company's transformers[2] are those which possess greatest interest for the engineer. The efficiency was determined by an original method in which the losses are measured directly and compared with the input—a method susceptible of much greater accuracy than the comparison of input and output. An essentially similar device for determining the efficiency of dynamos had been described in the joint Paper of 1896 referred to above.

In 1885 John Hopkinson published the results of some very careful experiments on the magnetic properties of various samples of iron.[3] These were undertaken partly in order to supply the information necessary for an adequate discussion of the theory of the dynamo; and for many years they were largely used in dynamo design. It was natural to Hopkinson to regard a subject which he had first investigated, in part, for practical ends, as the best possible material for pure scientific research, and his laboratory work between 1886 and 1890 was chiefly concerned with the magnetization of iron. The most important of these experiments were those on the effect of heat on this phenomenon, carried out in 1889.[4] They showed that the disappearance of the distinctive magnetic qualities of iron occurred at the same temperature as a number of other sudden changes of state, such as that known as recalescence. For his researches in magnetism Hopkinson was in 1890 awarded a Royal Society Medal.

Until 1891 Hopkinson did not carry out any constructive engineering work of great importance. In that year, however, the Corporation of Manchester asked him to advise as to the electric lighting of that city. He reported on it, and in the two following years acted as Consulting Engineer in carrying out the work. It was one of the largest electric-lighting schemes that had been undertaken in this country, and was from the first very successful. Hopkinson introduced several novel features; but perhaps his most important innovation was in the method of charging for the current. He had, as early as 1883, pointed out how large a proportion the fixed charges would bear to the running charges in electric supply, and he obtained the introduction into some Provisional Orders of that date of a clause

[1] Proceedings of the Royal Society, 1887, p. 167.
[2] Published in 1892.
[3] Philosophical Transactions of the Royal Society, 1885.
[4] *Ibid*, 1889.

sanctioning "a charge which is calculated partly by the quantity of energy contained in the supply and partly by a yearly or other rental depending upon the maximum strength of the current to be supplied." This principle was, however, not introduced into practice until Hopkinson caused it to be adopted at Manchester. Since then it has been followed in nearly all electric-lighting stations in this country. The success of the Manchester electrical works naturally brought more employment of the same kind, and during the next five or six years Hopkinson was responsible for the erection of many electric-lighting installations in this country.

John Hopkinson had from a very early period taken a great interest in electric traction. In 1883 he patented the series-parallel control, describing it as applied to a hoist; and in 1885 he invented a system of surface contacts for tramways. He acted as consulting engineer to the contractors for the electrical part of the City and South London Railway. His most important work of this kind was, however, done in 1896, when he superintended the making of the Kirkstall and Roundhay tramway at Leeds. He had carefully observed tramway practice abroad, and did not introduce any novel features of importance into this line. It was, however, very successful, and at the time of his death he was engaged in carrying out large extensions. During the last two years of his life electric traction formed the greater part of his constructive work.

Some mention should be made of Hopkinson's services in the cause of engineering education. He did not hold any educational appointment until he became Professor at King's, but he had strong views on the subject to which he gave effect in many ways. He was especially interested in the development of the Engineering School at Cambridge, and was one of the largest subscribers when it was started. His views on the proper functions of mathematics are well known; he regarded the Engineering Tripos, in the form to which Professor Ewing has brought it, as the best possible fulfilment of them. He was also a member of the Senate of London University. At King's College he did not do any actual teaching; but he allowed the more promising students, to a large extent, to carry out the experiments connected with his researches. Those whom he had educated and tried in this way he recommended for the electrical engineering positions which his position as Consulting Engineer enabled him to control. The results are a striking testimony both to the influence he had over his students and to the judgment with which he selected them. Among those whom he taught and helped as young men are perhaps to be found his chief mourners.

Dr. Hopkinson was elected an Associate of the Institution on the 4th December, 1877, and was transferred to the class of Members on the 18th April, 1882. Since 1895 he occupied a seat at the Council table. He was also a Fellow of the Royal Society, a Member of Council of the British Association and of the Institution of Mechanical Engineers, a Member of the Physical Society and of the Royal Institution, and twice served the office of President of the Institution of Electrical Engineers. At his suggestion a Volunteer Corps of Electrical Engineers was formed, of which he was Major.

Dr. Hopkinson's premature death, at the age of 49, was the result of an Alpine accident. He was well acquainted with the mountains of Switzerland, and an experienced climber. On the morning of the 27th August, 1898, accompanied by his second son, John, and two elder daughters, he started to ascend the Petite Dent de Veisivi, a peak in the Val d'Hérens, which runs south from Sion in the Rhône Valley. The mountain was well known to him, and the cause of the accident which resulted in the death of father and children must remain unexplained.

This notice may well close with a tribute paid to the memory of Dr. Hopkinson by Sir John Wolfe Barry, before delivering an Address as President of Section G of the British Association meeting held at Bristol in the autumn of 1898. It ran as follows:—

"I wish at the commencement of the proceedings this morning to refer to the loss which the world of science has sustained in the untimely and lamentable death of my friend, Dr. John Hopkinson. This tragedy was one of a most unusual kind, and I think I am not saying too much if I say it has touched the hearts of everybody in Great Britain. When we recognize that the father, son, and two daughters were suddenly swept into eternity by this dreadful accident, I am sure that our hearts go out in respectful sympathy and heartfelt condolence to Mrs. Hopkinson and the remainder of Dr. Hopkinson's family. To us in the scientific world the loss is certainly irreparable. Dr. John Hopkinson was a man of most unusual attainments. He was senior wrangler at the University of Cambridge, and Smith's prizeman, and he had the highest gifts of intellectual power, combined with great practical knowledge, and at the time of his death with most ripe experience. He was admired throughout the whole of the scientific world of Great Britain. But I think I am not going too far when I say he was an ornament to the world of science, whether it be European or American, and that his name

was respected in every part where men of science are qualified to form an opinion upon an individual's merits. I can speak of my departed friend with perhaps stronger feelings. I have come under the magic of his personal charm; I have been able to realise his charming modesty, combined with his great attainments and his many social gifts. He was a Member of the Council of The Institution of Civil Engineers, on which I had the honour of serving with him for many years, and he was a Member also of the Council of the British Association. He was a personal friend of many of those who hear me, and I am sure they will agree that I have not said a word too much in bringing before this section the great loss which has been sustained by the death of John Hopkinson. I am sure I shall have my own sentiments endorsed when I offer this small tribute of affectionate admiration to a man of science who has been one of the brightest ornaments of the century."

HENRY DANIEL MARTIN[1] was born in Greek Street, Soho, London, in the year 1811, and was sent at an early age to a preparatory school in the neighbourhood, afterwards proceeding to a school in King Street, St. James's, then well known for its success in mathematical studies. At the age of 15 he was articled to Mr. Thomas Nicholls, who had a large practice as an architect and surveyor. During his pupilage, in the year 1831, he obtained a studentship in the Royal Academy, then situated at Somerset House in the Strand, intending to pursue the separate calling of architect. But while assisting Mr. Wilkins, R.A., in making the drawings and estimate for the National Gallery, circumstances changed this intention, and he was appointed to succeed Mr. James Walker, Past-President, to take charge of the works at the East India Docks. Shortly after, when that Company was amalgamated with the West India Dock Company, he was entrusted with the additional charge of the works at that establishment, being appointed engineer to the united companies. In that capacity he projected and carried out works of considerable magnitude, and this connection naturally led to his being engaged in the construction of works of the same kind on the River Thames and elsewhere, especially of docks, both wet and dry, wharves, jetties, quays and warehouses.

[1] This notice, with the exception of some slight additions, is autobiographical.

In the year 1846 Mr. Martin was requested by the then London and Birmingham Railway Company (subsequently re-named the London and North-Western), in conjunction with the dock companies, to lay out a line connecting that system of railways with the docks and the port of London. When the Bill dealing with that project was lodged in Parliament it was introduced as a means of promoting the conveyance of merchandise only, without any expectation of its becoming available for the service of passenger traffic, but long before the line was completed, the suburban districts through which it passed had increased in population so rapidly as to necessitate providing for its accommodation as a passenger line, and consequently the improvement of the physical features of the undertaking, the provision of frequent shipping stations, the making of approach roads and other variations had to be made to adapt the railway to the altered conditions of traffic. This line, now known as the North London Railway, became the base of extensions to various parts of the metropolis and its surroundings, including a continuation to the heart of the city of London, the line passing through one of the most crowded neighbourhoods in the metropolis. At the Port of London terminus the principal undertakings consisted of the laying down lines of rails at the quays of the docks for the use of vehicles employed in receiving or discharging cargoes from or into vessels lying alongside, and the further delivery from or into the warehouses, the whole of the operations being facilitated by the expeditious and economical means of extensive hydraulic machinery in substitution for the tardy and costly operation of manual labour then in use. Further docks and extensive warehouses were built for special goods and mineral traffic, in addition to extensions of the lines, the erection of the terminal station at Blackwall, and the construction of similar works at other places both for passenger and merchandize uses.

In the year 1855 Mr. Martin was appointed Consulting Engineer to the East India Company, and while holding that position he designed various important works, including bridges, barracks, roads, machinery, etc., more especially such as were required during the period of the Mutiny. Many were of an exceptional character, as great rapidity of construction in some cases was of the utmost importance, and necessitated work of a peculiar and novel kind to suit the unusual conditions. An interesting feature of this work was the energy which was shown by the men employed at the various establishments where the work required for transmission to India during the Mutiny was carried out

night and day with unceasing vigour and the most zealous alacrity. That appointment he held till the abolition of the company, the transference of its powers to the Imperial Government, and the consequent employment of military officers for engineering purposes.

In his later years Mr. Martin was engaged in making a survey and in improving the navigation of the River Medina and its estuary, and as he had constructed several quays and bridges in various parts of the Isle of Wight, he turned his attention to the introduction of railways into that island, and laid out a system of lines, most of which were constructed under his superintendence.

Mr. Martin died on the 25th September, 1898, at his residence, Halberry, Newport, in the Isle of Wight, at the age of 87. He was at the time of his death the "Father of the Institution," having been elected an Associate on the 20th March, 1838, and transferred to the class of Members on the 4th May, 1858.

MURDOCH PATERSON, son of Mr. Donald Paterson, of Inshes, near Inverness, was born in September, 1826. Having been educated in the parish school of Culcabock, and in the Royal Academy, Inverness, he passed two years in the office of Mr. John Mackenzie, banker, where he received a thorough commercial training which was in after years of great use to him. Happily for himself he decided that his career was to run in quite a different direction, and he found his true vocation in the office of the late Mr Joseph Mitchell, to whom he was bound as apprentice in 1846. There was no office in the North at that period in which he could have obtained a more comprehensive training, Mr. Mitchell being the Government Engineer for the construction of roads, bridges, harbours and buildings in the Highlands.

When the railway mania reached the North, Mr. Paterson, though but little over twenty years of age, became engaged in many of the enterprises then undertaken in that district. In 1851 he left Mr. Mitchell and started with a firm of contractors who had the work of enlarging the harbour accommodation at Inverness. The firm, however, failed, and young Paterson, so great was the confidence placed in him, was appointed by the harbour trustees to carry out and complete the works, which he did to their entire satisfaction.

The present system of the Highland Railway was begun in a

small way in 1854 by the construction of the line from Inverness to Nairn, and on this undertaking Mr. Paterson was actively engaged under Mr. Mitchell, the Engineer to the Company.[1] The first turf of the Nairn line was cut by the Countess of Seafield on the 20th September, 1854. In rapid succession followed the expansion of the railway from Nairn to Keith, from Inverness to Invergordon and Bonar Bridge, and of the main line from Forres to Perth—a work which made the Highland Railway the main artery between the north and south of Scotland. These lines were constructed in less than ten years. Mr. Paterson was in charge of the construction of the line from Inverness to Keith and Bonar Bridge, and of the trunk line from Forres to Dunkeld.

In 1862 Mr. Mitchell took the brothers William and Murdoch Paterson into partnership, the firm being known as Joseph Mitchell and Company. Mr. Mitchell retired in 1867, in which year the Sutherland lines from Bonar Bridge to Golspie were designed under the superintendence of Mr. Paterson, who now entered on an independent career and had full charge of the Dingwall and Skye line, including Parliamentary work and construction, until its completion in 1870. The Sutherland lines were completed in 1871 as far as Helmsdale, Mr. Paterson in that year, with the assistance of a large staff, surveying under great difficulties the 66 miles between Helmsdale, Wick and Thurso in less than one month.

On the opening of the Caithness line from Helmsdale to Wick and Thurso, which was taken over by the Highland Railway Company in 1874, Mr. Paterson was appointed Chief Engineer of that Company, which post he held until his death. Under his supervision the Buckie line, Black Isle, Strathpeffer branch, Hopeman and other railways were constructed; besides the surveys of various proposed lines in all parts of the North. The construction of the new direct line from Inverness to Aviemore, which was opened in November, 1898, Mr. Paterson practically saw completed, and this work occupied his last days, his death taking place on the 9th August, 1898, in the house built for the agent at Culloden Moor station on that line. The Aviemore direct line is about $33\frac{3}{4}$ miles in length, and shortens the journey between Inverness and the South by some 26 miles. The viaducts over the Findhorn and Nairn Rivers on this line are most important constructions. The former, which is 445 yards long

[1] Minutes of Proceedings Inst. C.E., vol. lxxvi. p. 365.

and 141 feet from the bed of the river to rails, consists of nine spans, each 130 feet long, resting on eight piers and two abutments of masonry, with two arches of 25 feet span at each abutment. The Nairn viaduct is perhaps the largest structure of its kind in Scotland, the total length being 600 yards and the greatest height above the river bed 130 feet. The main arch through which the water flows has a span of 100 feet, and the twenty-eight subsidiary arches have each a span of 50 feet. The Nairn and Findhorn viaducts form lasting monuments of Mr. Paterson's skill.

Mr. Paterson designed the water-supply to Inverness, the new bridge over the River Ness, and a number of other works too numerous to mention. Mr. Paterson possessed great independence of character, though he was not over assertive. Remarkably careful in his estimates and most conscientious in his various dealings, he was a loyal officer of the Highland Railway Company, and his staff, to whom he was always most kind and considerate, looked to him with feelings of the utmost affection, and were inspired by his example to still greater devotion to duty. In private life he was a warm and most steadfast friend.

Mr. Paterson was elected a Member of the Institution on the 3rd February, 1874.

ROBERT SINCLAIR,[1] who died at Florence on the 20th October, 1898, was one of the engineers prominently connected with early railway history, of whom few are now left. Mr. Sinclair had so long retired from the active practice of the profession, that he was little known to the present generation of engineers, but he was one who in his time took a most prominent part in the development of locomotive practice and in railway affairs generally.

Robert Sinclair was the son of the late Mr. Alexander Sinclair, a prominent London merchant trading to the Cape of Good Hope and the founder of the present firm of Sinclair, Hamilton, and Co. He was born on the 1st July, 1817, and was thus in his eighty-second year at the time of his death. After being educated at Charterhouse under Dr. Russell, he decided on following the profession of an engineer, and served an apprenticeship with

[1] This Notice has been abridged, by permission of the Editor, from *Engineering* of the 11th November, 1898.

Messrs. Scott, Sinclair and Co., of Greenock, his uncle, Mr. Robert Sinclair, being a member of that firm.

On the completion of his apprenticeship he obtained employment in the office of Mr. W. B. Buddicom, who was Locomotive Superintendent of the Grand Junction Railway, and afterwards at Crewe, to which place the locomotive shops of that Company were removed. This association with Mr. Buddicom materially influenced his future career. At that time Mr. Locke was the engineer of the Paris and Rouen Railway, and in 1841 he invited Mr. Buddicom to erect works at Rouen for the construction of rolling stock for that line. This invitation was accepted, and the firm of Allcard, Buddicom and Co. was formed and constructed extensive works at Sotteville. Pending their completion smaller works were established at Les Chartreux, a suburb of Rouen, and to these Mr. Sinclair was appointed as Manager, he leaving Crewe shortly after Mr. Buddicom.

This position at Rouen Mr. Sinclair held for some time, but, in 1844, Mr. John Errington, of Messrs. Locke and Errington, offered him, on the death of Mr. Ilbery, the position of Locomotive Superintendent of the Glasgow, Paisley and Greenock Railway, and this offer he accepted. A year or two later that line was taken over by the Caledonian Railway Company, and Mr. Sinclair was appointed Locomotive Superintendent of the whole Caledonian system, to the duties of which post were added in 1852 those of General Manager. His success on the Caledonian Railway was remarkable, and the manner in which the financial position of the company improved under his care was in itself sufficient to establish his reputation.

In 1856 Mr. Sinclair left the Caledonian Railway to become Locomotive Superintendent of the then Eastern Counties Railway, a line which afterwards, by fusion with the Eastern Union and East Anglian Railways, &c., formed the Great Eastern system. About a year after his joining the Eastern Counties Railway, Mr. Sinclair, on the retirement of Mr. Peter Bruff, was appointed Chief Engineer, as well as Locomotive Superintendent, and these two offices he held until he resigned in 1866. During the latter part of that time Mr. Sinclair also acted as Engineer of certain new lines connected with the Great Eastern Railway system, for which powers were being sought in Parliament, amongst them being the East London line to Liverpool Street. At the London Exhibition of 1862 one of his engines, constructed by Messrs. Robert Stephenson and Co. for the Eastern Counties Railway, was exhibited.

After leaving the Great Eastern Railway, Mr. Sinclair established himself in independent practice in Westminster, but, unfortunately, delicate health necessitated his leaving London, and after residing some time in Devonshire, he retired to Italy, living first for some years in Rome, and subsequently at Florence.

Owing to his early training at Crewe, Mr. Sinclair's locomotive practice was naturally founded on that of Buddicom and Allan, and he was, so long as he was in practice, a strong advocate for the outside-cylinder type of engine. He was, however, no mere copyist, but had abundant originality and a strong sense of the mechanical fitness of things, qualities which put their impress on his designs. For instance, he designed in 1859 for the Great Luxemburg Railway, a class of eight-wheeled passenger engines (of which the first was built by Messrs. Robert Stephenson & Co., of Newcastle), with small leading and trailing wheels, and four-coupled wheels between—a type of locomotive which has since become an established feature in Belgian practice. This engine was provided with a two-wheeled Bissel truck at the leading end, and was, it is believed, the first locomotive to which this form of truck was applied, at all events, in Europe. Mr. Sinclair subsequently adopted a similar arrangement for some eight-wheeled tank engines built for the Great Eastern Railway.

It is only those familiar with locomotive details some forty years ago who can fully appreciate the influence of Mr. Sinclair's work on modern practice. In those days locomotive engineers generally were far more afraid of a little weight in their engines than they now are, and there was hence a tendency towards excessive lightness. Mr. Sinclair did not share these views. He was an advocate for large wearing surfaces and ample strength, and did not fear a little extra weight if he thought it necessary to give efficiency and durability. Nowadays the proportions of valve gear, &c., which Mr. Sinclair used, would not appear unusual, but forty years ago they provided areas of bearing surfaces far in excess of general practice.

A noticeable feature introduced by Mr. Sinclair, which has now been generally accepted, is the well-known conical chimney, a design he brought out when on the Caledonian Railway. Mr. Sinclair also took a prominent part in the provision of efficient shelter for engine-drivers. Forty years ago the so-called "weather-plates" or "weather-boards" in use provided very poor protection for the men, and many engines were even without these. Mr. Sinclair first enlarged the weather-plates, fitting them with look-out glasses, and bending them over at the top, so as to afford

shelter when the engine was standing, while shortly afterwards he commenced fitting his engines with regular "cabs," more or less following American practice.

Mr. Sinclair was one of the pioneers in the use of steel for locomotive details; and he was one of the first to use steel freely in this country for tires and axles. Mr. Sinclair was also one of the first regular users of the injector in locomotives, and he did not hesitate to abolish pumps entirely on engines fitted with them, a policy which had most satisfactory results, and convinced the drivers of the reliability of the new appliance.

Nowadays, when the system of working to standard patterns and gauges is so firmly established on railways, it is difficult to understand how any other system could be endured. But forty years ago matters were in a very different state, and every railway had in use an almost endless variety of engine and rolling-stock details, introduced from time to time by different builders. The Great Eastern Railway was no exception to the general rule, and the task of remedying this state of affairs and establishing certain standards was an exceedingly difficult one which Mr. Sinclair carried out with great judgment and success. For his own engines he insisted on rigorous working to gauges and thorough interchangeability of parts, and he certainly is entitled to share with the late Mr. Ramsbottom and others the credit of the introduction of the modern system.

Mr. Sinclair was an admirable leader of men. Absolutely straightforward in all his dealings, possessed of great firmness and kindness of heart, and with a strong sense of justice, he was sincerely beloved and respected by all who served under him. Apart from his professional attainments, he was a man of great culture, and during the latter years of his life devoted himself much to the study of Italian literature. To those who had the privilege of his friendship, his death will create a blank which will not be easily filled. He married Miss Jean Campbell, a daughter of the late Mr. John Campbell, of H.M. Customs, Greenock.

Mr. Sinclair was elected a Member of the Institution on the 13th April, 1858.

GEORGE E. WARING, Junior, was born in Poundridge, New York, on the 4th July, 1833. He was educated at College Hill, Poughkeepsie, New York, and then studied agriculture on the Mapes Experiment Farm. During the winter of 1854 he lectured

on agricultural subjects throughout Maine and Vermont. In 1855 he took charge of Horace Greeley's farm at Chappaqua, New York, remaining there until 1857, when he was appointed agricultural and drainage engineer of Central Park, New York City, which position he occupied until the beginning of the Civil War. In May, 1861, he was given a commission as Major of the Garibaldi Guard, with which he served three months, and in the following August he was appointed Major of Cavalry under General John C. Fremont, then in St. Louis. He raised six companies of cavalry under the name of the Fremont Hussars. These and the Benton Hussars were afterwards consolidated to form the 4th Missouri Cavalry, of which Waring was commissioned Colonel in January, 1862. With that regiment he served throughout the war, principally in the south-west.

In 1867 Colonel Waring settled in Newport and assumed control of the Ogden farm. He introduced Jersey cattle into the United States and founded the American Jersey Cattle Club. He devoted himself to agriculture, cattle-breeding and drainage until 1877, when his engineering work assumed such proportions as to require his undivided attention. Since that date he has been in active practice as a drainage and sewerage engineer.

After the yellow fever epidemic of 1878–79, which cost 5,635 lives in Memphis alone, Colonel Waring devised, as a means of getting rid of the filth of that city—and the only means for which its bankrupt people could pay—a system of small pipe sewers, a strictly "separate" system, designed to receive nothing but household wastes, automatically flushed at regular intervals and with special provision for ventilation. His plans were adopted in the face of bitter criticism, and the sewers were built. Since that date yellow fever has never obtained a foothold in Memphis. The system, universally known as "the Waring system," has been extensively used in the towns and smaller cities of the United States.

In June, 1879, Colonel Waring was appointed expert and special agent of the Tenth Census of the United States in charge of the social statistics of cities. In 1882 he became a member of the National Board of Health. He was also an Honorary Member of the Royal Institute of Engineers of Holland, Fellow of the Sanitary Institute of Great Britain, Member of the American Public Health Association, and Corresponding Member of the American Institute of Architects. He planned and supervised the sewerage of more than forty towns and cities in the United States, and invented numerous sanitary devices, chiefly in

connection with the drainage of houses and towns. From 1895 to 1898, as Commissioner of Street Cleaning of New York, he substituted scientific knowledge and business-like methods for the indifference and mismanagement which had prevailed under political control, and inaugurated reforms which have since been adopted by many other cities. In September, 1898, he was charged by the government with an investigation of the sanitary condition of Havana and other Cuban ports. While engaged in that work in Cuba, he was stricken with yellow fever, and died in New York on the 29th October, 1898.

Colonel Waring was a voluminous writer and a frequent contributor to various journals and magazines. His larger literary works are:—"Elements of Agriculture" (1854), "Draining for Profit and Draining for Health" (1867), "Book of the Farm" (1870), "A Farmer's Vacation" (1875), "Whip and Spur" (1875), "Sanitary Drainage of Houses and Towns" (1876), "The Bride of the Rhine" (1877), "Village Improvements and Farm Villages" (1877), "Sanitary Condition of City and Country Dwelling Houses" (1877), "Tyrol and the Skirt of the Alps" (1879), "How to Drain a House" (1885), "Sewerage and Land Drainage" (1888), "Modern Methods of Sewage Disposal" (1894), "Aerial Navigation" (1894), and "Street Cleaning and the Disposal of a City's Waste" (1898).

He was elected a Member on the 5th December, 1882, and four years later contributed to the Proceedings a Paper entitled "Siphon-Outlet for a Low-Sewer District, Norfolk, Virginia, U.S.A."[1]

WILLIAM LAWRENCE WILLIAMS served an apprenticeship to Messrs. Thomas Brassey & Co., at the Canada Works, Birkenhead, from 1863 to 1868, and for three years afterwards was employed in those works. He there acquired a thorough practical training as an engineer, being engaged on the construction of bridge work, locomotives and large plant for the Grand Trunk and other lines in America. He left the Canada works in 1871, to become chief assistant and subsequently works manager to Messrs. Brown Brothers, hydraulic engineers, of the Rosebank Ironworks, Edinburgh, where for ten years he was responsible for many important contracts, including hydraulic machinery, at the Hamburg, Ayr,

[1] Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 429.

Bo'ness, and Cardiff Docks, and for the North British Railway Company.

Leaving Edinburgh, in 1880, Mr. Williams started practice in Westminster as a consulting engineer, and soon succeeded in securing an extensive connection. His work consisted mainly in designing hydraulic and steam machinery, steam-tugs, barges, &c. He invented an hydraulic capstan and a steam reversing engine which were considerably used, and he fitted refrigerating plant into barges on the river. He was consulting engineer to the London and Tilbury Lighterage Company, Messrs. Wm. Cory & Son, and other important companies. For Messrs. Cory & Son he designed, in conjunction with Mr. Henry Adams, a crane of an entirely new pattern, which was erected on their derricks for loading barges on the outside of the vessel being discharged. He assisted Messrs. Hunter and English in the design of hydraulic machinery, and designed auxiliary engines for the steamers of the Pacific Steam Navigation Company, the London and North Western Railway Company, the City of Dublin Steam-Packet Company, and the East and West India Docks Company.

Mr. Williams died in Edinburgh on the 28th August, 1898, at the age of 50. He was elected an Associate Member on the 19th May, 1885, and was transferred to the class of Members on the 8th March, 1887. He was also a Member of the Institution of Mechanical Engineers.

JOSEPH WILLIAM WILSON, son of the Rev. William Wilson, D.D., Vicar of Walthamstow, Essex, and later Vicar of Over Worton, Oxfordshire, was born on the 11th October, 1829. He was originally destined for the Church, and was entered with that intention at Wadham College, Oxford. However, as a lad, he had evinced a strong inclination towards engineering, and his father was persuaded to place him as a pupil under his cousin, Mr. (afterwards Sir) Charles Fox, of the firm of Fox & Henderson, Birmingham. At the expiration of his pupilage Mr. Wilson acted for them as an Assistant Engineer on the construction of the Exhibition Building of 1851, having charge of the machinery employed in the preparation of the large quantity of timber required for the structure. He introduced several important improvements in those machines.

After this, Mr. Wilson, in partnership with his brother-in-law,

Mr. S. H. F. Cox, erected and opened at Birmingham the Oldbury Engineering Works, where from 300 to 400 men were employed in turning out important pumping and other engines and machinery, including large quantities of stamps and other apparatus for use in the Californian gold-fields. After a few years his health temporarily gave way, and he retired from the Oldbury Works and established himself at Banbury, where, as consulting engineer to the timber works there, he had further scope for the exercise of his inventive genius, and in 1855 he patented the well-known circular gouge and disk-paring tools for timber machinery, for which he received, from the hands of the Prince Consort, the Medal of the Society of Arts.

In 1857 Mr. Wilson came to London and commenced to practise as a consulting engineer, carrying out, latterly in conjunction with his eldest son, various pier, water and other works at Starcross, Hampton, Hunstanton, Teignmouth, Shoreham, the Isle of Wight, High Wycombe, Westward Ho and other places.

Mr. Wilson had always taken special interest in the mechanical as well as in the theoretical training of his pupils, having pattern and fitting shops attached to his offices in Westminster, and in 1872, in order to further develop this idea, he persuaded the Directors of the Crystal Palace Company, to inaugurate their School of Practical Engineering. There he and his sons devoted themselves to providing for students a personal training in the combined theory and practice of the earlier stages of their professional career. Mr. Wilson possessed in a high degree the faculty of winning the affection of his pupils as well as of imparting to them his varied professional experience; and he lived to see many of them rise to important positions in the engineering world.

After occupying for twenty-six years the position of Principal of the Crystal Palace Engineering School, Mr. Wilson contracted a chill in Scotland in August last, from the effects of which he gradually grew weaker, and finally passed peacefully away at his residence at Kenley, Surrey, on the 5th November, 1898, in the 70th year of his age. Mr. Wilson was elected an Associate of the Institution on the 2nd February, 1869, and was transferred to the class of Members on the 14th January, 1879. He was also a Member of the Institution of Mechanical Engineers, a Fellow of the Royal Colonial Institute, and a Vice-President of the Junior Engineering Society.

WILLIAM WILSON, born at Alnwick, Northumberland, on the 20th January, 1822, was the youngest son of Mr. George Wilson, who was one of the proprietors of the mail-coaches then running between London and Edinburgh. At the age of sixteen he was articled to Mr. John Bourne, of Newcastle-on-Tyne, and the work upon which he was engaged at that period led to an interesting episode in his relations with George Stephenson, who on one occasion took exception to some levelling done by Wilson for the Newcastle and Berwick line. An inspection of the ground compelled Stephenson to admit the accuracy of the work, and, as a memento of the occasion, he presented Wilson with the watch he was carrying.

After leaving Newcastle Mr. Wilson came to London, and was occupied on some works for Messrs. Fox and Henderson, one of the first being the roof of the old station at Dover. He was next occupied under Sir John Fowler (then Mr. Fowler) on the Manchester, Sheffield and Lincolnshire (now the Great Central) Railway, and subsequently on the Worcester and Wolverhampton line and the Wolverhampton Joint Station.

Mr. Wilson then became associated with Sir John Fowler in the construction of the Victoria Station and the Pimlico Railway, which included the Victoria Bridge over the Thames. This work was carried through with great rapidity, the first stone of the bridge being laid on the 9th June, 1859, and the first train passing over on the 9th June, 1860. For a description of the work which Mr. Wilson subsequently presented to the Institution, he was awarded a Telford medal and premium.[1] Among other works in which Mr. Wilson was associated with Sir John Fowler may be mentioned the Millwall Docks, the Hammersmith and City Railway, and the West London Extension of that line as far as Addison Road Station.

In the enlargement of Victoria Station, the widening of the Victoria Bridge over the Thames, and the construction of branch railways, Mr. Wilson acted between the engineer of the widening (Sir Charles Fox) and the contractors (Messrs. Peto and Betts), the first stone of the bridge being laid on the 22nd February, 1865, and the first locomotive passing over it on the 1st August, 1866. He also acted for Messrs. Peto and Betts, Messrs. Kelk, and Messrs. Waring on the Metropolitan Railway Extension to Notting Hill and Brompton, the Metropolitan District Railway and the Metro-

[1] Minutes of Proceedings Inst. C.E., vol. xxvii. p. 55.

politan Extension to Tower Hill, and for Sir John Kelk on the widening of the Metropolitan Railway from King's Cross to Farringdon Street. In conjunction with Sir John Fowler and Mr. Abernethy he was engaged for some years upon the "English and Continental Intercommunication," a scheme for huge ferry-boats to carry trains between France and England; and, at the instance of the Duke of Sutherland and Sir John Fowler, he visited Rome to advise as to the rectification of the Tiber.

Among the works on which Mr. Wilson subsequently acted as engineer may be mentioned the Aylesbury and Buckingham Railway, the Banbury and Cheltenham Direct Railway, the Jerez and Algeciras Railway, and the Folkestone Pier. He reported on engineering enterprises in the United States and Canada, and in many European countries, and frequently gave evidence on railway, dock, and other projects before Parliamentary Committees.

Mr. Wilson died at his residence, 19 Applegarth Road, West Kensington, on the 20th September, 1898. He was twice married; first to Hannah, daughter of Mr. John Kirkby, of Sheffield, and secondly, in February, 1857, to Flora Maria Ellen, eldest daughter of the late Rev. W. Alfred Dawson, M.A., of Christ College, Cambridge. Those who best knew Mr. Wilson appreciated his worth and practical goodness. He combined with engineering ability and great skill as a draughtsman habits of industry and a sense of duty which allowed no personal consideration to interfere with his work.

Mr. Wilson had at the time of his death been a member of the Institution for nearly fifty years, having been elected on the 1st May, 1849.

CHARLES ADCOCK, born on the 15th October, 1860, was a native of Leicestershire. He was educated at Appleby Grammar School, and in 1877 was articled to Mr. Clement Dunscombe, who was then Borough Engineer of Derby. On the completion of his articles in 1880 he was engaged as an assistant by Mr. Dunscombe, who had become City Engineer of Liverpool. In that capacity he was employed for nine years on various municipal work, including the construction of tramways and the improvement of streets. In 1889 Mr. Adcock was appointed County Surveyor of West Sussex, and while holding that post was responsible for the organisation of a new system of road management, for the reconstruction of several bridges, and for the erection of county buildings.

Owing to ill-health Mr. Adcock was compelled to resign his appointment in 1896, and acting on medical advice he left England for Western Australia, where he filled various posts in the Public Works Department. He was at first in the Sewerage and Water Supply Branch, where he was in charge of the construction of the new reservoir at Fremantle, and finally in the Harbours and Rivers Branch. The change of climate did not, however, effect the desired improvement in his health, and Mr. Adcock died at Guildford, Western Australia, on the 15th July, 1898, at the age of 37. He was elected an Associate Member on the 2nd April, 1889.

JAMES BELL, born in Edinburgh on the 3rd December, 1852, was a son of the late Mr. George Bell, a well-known jeweller of that city. After leaving school he served an apprenticeship of five years, from 1868 to 1873, with Messrs. George and William Bertram, engineers and millwrights, of St. Katherine's Works, Edinburgh. During that period he attended certain of the technical classes at the University of Edinburgh. In November, 1873, he became an apprentice with Messrs. John and G. H. Geddes, mining engineers, also of Edinburgh, with whom he remained until 1880 as an assistant. In July of the latter year he was engaged by Messrs. Robert Addie and Sons, of the Langloan Ironworks, Coatbridge, to take charge of the engineering and surveying department of their extensive ironstone and coalpits. He held that post until April, 1881, when it became necessary to send an engineer and manager to Spain to take charge of the mines, inclines and railways of the San Fermin Mining Company, of Bilbao, in which Messrs. Addie were interested, and Mr. Bell was selected for the appointment. The mines had been newly acquired, and his first work was to connect them with the Galdames Railway, and to open and develop them. In addition to that work, which he carried out with energy and skill, he had to conduct frequent negotiations with the local and provincial authorities, and in these he displayed great ability and tact. After the mines were opened up he had entire charge of the working of them until 1893, when the Company resolved to discontinue operations in Spain.

From June, 1893, Mr. Bell acted as Engineer to the Luhrig Coal and Ore Dressing Appliances, of Westminster, in charge of the design and erection of their plants and engineering work. In

July, 1898, he suffered a severe illness, which left his heart in a weak state, and on the 27th October following he succumbed from syncope. Mr. Bell was elected an Associate Member on the 3rd December, 1895.

JOHN WILLIAM TOWNSEND BOYS, born in Christchurch, New Zealand, on the 4th May, 1860, was the son of Mr. J. G. Boys, one of the first settlers of Canterbury in that colony. He was apprenticed to Mr. C. Napier Bell in 1877, and was employed on the sewerage works of Christchurch and on the dock works of Port Lyttelton, both then being carried on by Mr. Bell. Mr. Boys was then employed on railway works in Tasmania, and shortly afterwards was appointed to superintend the construction of the Emu Bay concrete breakwater, then being carried out from the designs of Mr. Bell. Mr. Boys next removed to Sydney, N.S.W., where he was engaged on railway surveys, but soon after he was appointed to superintend the construction of the sewerage works of North Sydney, where he carried out very heavy works in tunnel through some miles of sandstone hills under the city. On the completion of those works, he was engaged as Engineer to the Paramatta borough and county district, but shortly after he went to Perth, Western Australia, where he was appointed to assist Mr. Bell in preparing plans for sewerage works for Perth and Fremantle. In 1898 he fell a victim to typhoid.

Mr. Boys was a well-trained engineer of considerable attainments—painstaking, assiduous and intelligent. He was distinguished for his gentlemanly manners, integrity of character, and thorough trustworthiness in everything he undertook. He was elected an Associate Member on the 2nd April, 1889.

DAVID GEORGE DAVIES, born on the 23rd January, 1859, was the only son of the late Mr. David Davies, of Swansea. He was educated at Thistleboon School, Oystermouth, and served articles with Mr. Hortensius Huxham of Swansea, civil and mining engineer, with whom he subsequently remained as an assistant. From 1879 to 1882 he was engaged as an assistant to Mr. Joseph Kincaid, of Westminster, on work in connection with various railway and tramway undertakings.

In September, 1882, Mr. Davies began to practise on his own

account, and during the following six years he was engaged on work in connection with the Corris Railway, the South West Junction Railway, the Torquay District Railway, and the West Metropolitan and other tramways in London. He also surveyed about 150 miles of light railways in various parts of Ireland for Mr. Kincaid, and in 1886 he went to Para, Brazil, as agent for an English company to report on and value a tramway.

In 1889 Mr. Davies gave up private practice, and from that year until 1892 he was employed by Messrs. Read and Campbell on the construction of the Mexican Southern Railway, at first as an Assistant Engineer, and subsequently in charge of one of the most difficult divisions of the line. In 1893, he was chief surveyor for Messrs. Livesey, Son, and Henderson in a party sent out by them to South Africa to report respecting the construction of the Beira to Salisbury Railway. In August, 1894, he was appointed Resident Engineer in Venezuela to the South Western of Venezuela (Barquisimeto) Railway Company, and he held that post until his death, which took place suddenly at Barquisimeto on the 20th October, 1898, the immediate cause being the pressure of a clot of blood on the brain.

Mr. Davies showed great ability, both as an engineer and organiser, and he gained the respect and esteem of all with whom he was brought into contact by his many sterling qualities. He was elected an Associate Member on the 12th January, 1886.

WILLIAM JAMES DOHERTY was born in 1834 at Buncrana, near Londonderry. On leaving school he served under Mr. James Bayliss, Engineer for Lough Swilly Reclamation Works. In 1856 he was in charge of the survey and laying out of the Londonderry and Lough Swilly Railway, and of the Derry Wharf contract. From the end of 1856 to 1858 he acted as the Contractors' Engineer on the Birkenhead Dock Works and on the Liverpool Docks, and then occupied for four years a similar position on the Hull Dock Works.

In 1863 Mr. Doherty started a business on his own account as a Contractor in Ireland. Among the undertakings he carried out in that capacity may be mentioned Graving and Dock Works, Queen's Quay, Waterworks and municipal improvements at Belfast; and at Dublin the reconstruction of Great Britain and a large portion of Sir John Rogerson's Quays, Carlisle and Essex Bridges, and the building of Butt Bridge, and Guinness's Wharf.

He also constructed the Dodder Valley Sewage Works, the piers at Teelin, Carrigaholt, and Clogher Head; Ardglass Harbour, Bray Harbour, Mullingar Barracks, and Carrickfergus Waterworks. The greatest of his undertakings was probably the Maryport Docks in Cumberland, and the pier at Workington was also constructed by him. He invented an improved pile-driving machine, which he set to work in the Liffey. He was one of the earliest to press for an improved system of education for Ireland.

Mr. Doherty was a High Sheriff of the City of Dublin, and was nominated for the Chief Magistracy in 1894. That office, however, he declined on medical advice, his health having for several years given cause for anxiety. In addition to his professional duties Mr. Doherty devoted much time to literary and antiquarian work, and wrote several Papers and two volumes—one treating of the antiquities of Tyrconnell and Innishowen, and the other of their connection with letters. He was a Member of the Royal Irish Academy and of the Institution of Civil Engineers of Ireland, and was elected an Associate of this Institution on the 7th December, 1875.

HERBERT EVINGTON, born at Hull on the 22nd January 1865, was the youngest son of Mr. C. S. Evington, builder and contractor, of that city. At the age of 16 he entered the drawing-office of Messrs. M. T. Shaw and Co., railway contractors, of Cannon Street, London, where he remained until August, 1882, when he was apprenticed to Messrs. Rose, Downs and Thompson, hydraulic and general engineers, of the Old Foundry, Hull. On the expiration of his pupilage, he was retained on the staff of that firm as a designer and draughtsman, ultimately becoming Chief Draughtsman, which post he held until his death. In addition to those duties, Mr. Evington of late years acted as Science Teacher to the Lincoln and Lindsey County Council, the Hull Young People's Institute, and the Hull School Board, for which posts he had qualified himself by attending evening classes. He had also acquired a knowledge of German, which greatly assisted him in dealing with his employers' business with that country. Mr. Evington died, after a short illness, on the 26th September, 1898. His natural modesty and unassuming manner had endeared him to a large circle of friends. He was elected an Associate Member on the 1st December, 1891.

HENRY MASTERTON, born on the 12th March, 1843, obtained his engineering training under the late Mr. Alexander Black, of Falkirk, to whom he was articled in 1857. He subsequently remained with that gentleman as an assistant, employed on work in connection with the Dunfermline and Queensferry Railway, the Grangemouth Railway and Docks, and the Falkirk Waterworks. In 1865 he came to Westminster, and entered the office of Mr. W. R. Galbraith. From 1866 to 1871 he was engaged as an assistant surveyor, under Messrs. Glasier and Son, on a large building estate at Hackney, preparing plans, superintending the construction of sewerage works, and laying out land for building purposes. In 1873 Mr. Masterton re-entered the service of Messrs. Galbraith and Church, by whom he was employed in the design of bridges and on various railway work. From September, 1881, to March, 1885, he acted as Resident Engineer, under Mr. Galbraith, on the Surbiton and Guildford and the Leatherhead branches of the London and South Western Railway, and in 1886 he was similarly occupied on the North Cornwall Railway, under Messrs. Galbraith and Church. On the completion of that work he became Resident Engineer on the construction of the Plymouth, Devonport and South Western Junction Railway from Tavistock to Devonport.

In 1890 Mr. Masterton was appointed by the Devon County Council Surveyor for the northern division of that county. In 1897 it was determined to divide the county into only two districts, and Mr. Masterton was appointed one of the two surveyors. Being permitted to undertake work on his own account, he carried out the laying of the water-main across the Tamar to Saltash, the widening of the Taw Vale Parade, and the laying of the impounding sewer at Barnstaple; and he conducted, for the Town Council of the latter place, the negotiations in connection with the construction of the Lynton and Barnstaple Railway. He also acted as Engineer to the Sutton Harbour Improvement Company at Plymouth. Mr. Masterton died at his residence, Boutport Street, Barnstaple, on the 18th September, 1898, from the effects of a chill. He was an able engineer, and was held in great respect by all who came in contact with him. He was elected an Associate Member on the 2nd February, 1886.

GEORGE NAPIER, only son of Mr. A. J. Napier, Writer to the Signet, was born at Edinburgh on the 30th May, 1869. He was educated at the Edinburgh Academy and at the Edinburgh University, after which he went through the three-years course at the Royal Indian Engineering College, Cooper's Hill, obtaining the diploma of the College. He then gained practical training with the firm of Messrs. P. and W. MacLellan, of the Clutha Ironworks, Glasgow. During 1894 and 1895 he was one of the staff of Messrs. Galbraith and Church, engaged on the construction of the graving dock at Southampton, and in January, 1896, he was appointed an Assistant Civil Engineer to the Admiralty on the construction of the Keyham Extension of H. M. Dockyard, Devonport, under Mr. Whately Eliot, the Superintending Civil Engineer. Towards the end of 1897, however, his health became so bad that he was compelled to resign that appointment. Early in the following year he went on a sea-voyage to the Cape, and on the 11th March, 1898, he died at Cape Town from a sudden attack of pneumonia. Mr. Napier combined practical common sense with an unusually sweet disposition, and his early death was greatly deplored by his colleagues on the Keyham Extension. He was elected an Associate Member on the 3rd March, 1896.

THOMAS CHEVELEY RAYNER, eldest son of the late Mr. Thomas Rayner, of Castle Hedingham, Essex, was born on the 30th October, 1840. After assisting his father, who was an extensive agriculturist in Essex, and being for some time in the office of a land agent and surveyor, he joined in 1861 the staff of the late Mr. William Munro, contractor, and was employed on the Colne Valley Railway and on the Tendring Hundred Railway during construction. In 1863–65 he was in charge of a considerable length of the Athenry and Ennis Junction Railway for the same contractor. He was engaged during 1866–68 on a 25-mile district of the State Railways in Denmark for the contractors, Messrs. Peto, Brassey, & Betts, and in 1869–70 on the East Hungarian Railways, under the late Mr. Charles Walker, for Messrs. Waring Brothers. From 1871 to 1876 he was occupied, partly on his own account, in connection with ironworks, mining, railways, &c., chiefly in South Wales. In 1877 he was again in Ireland as contractors' agent on the works of the Dungannon and Cookstown Railway, and in 1879 he was appointed to take charge

of the Banbridge Extension Railway, and afterwards of the Limavady and Dungiven Railway. On the completion of the latter line the directors retained him in their service as contractor for some extra works.

In 1885–86 Mr. Rayner carried out several contracts on his own account, including some difficult pier works on the Donegal coast for the Board of Public Works, Ireland. Early in 1887 he accepted an engagement as agent for the contractors of the Plymouth, Devonport and South-Western Railway Works, but relinquished that position shortly afterwards on being offered an appointment on the staff of the late Mr. T. A. Walker on the Manchester Ship Canal contract. There he was engaged as District Agent until the end of 1890, when he was appointed by the Belfast and County Down Railway Company Agent and Resident Engineer on the works of the Downpatrick, Killough and Ardglass Railway, which, together with the Newcastle loop line, he completed to the entire satisfaction of the Company. He was engaged on numerous other works in the North of Ireland until September, 1896, when he undertook for the Board of Public Works the supervision of the construction of Killybegs Pier, co. Donegal, which was completed in the following May. Unfortunately his health then began to fail, and, having to undergo a severe internal operation, he was unable to attend to work for nearly a year, but in March, 1898, he was entrusted by the Dublin University Boat Club with the execution of the works in connection with the new rowing course on the River Liffey. These he was able to complete satisfactorily, but, after long struggling against an internal complaint, he succumbed on the 17th November, 1898.

Mr. Rayner was loved and esteemed by all whom he employed. Somewhat reserved in disposition, he was hard to please in his choice of friends, and only selected those who were true and straightforward. He is greatly missed by many who had learned to appreciate his sterling qualities. He was elected an Associate on the 6th May, 1869, and was subsequently placed in the class of Associate Members.

LUCAS THOMASSON, son of Mr. John P. Thomasson, of Messrs. John Thomasson and Son, millowners, Bolton, was born on the 21st February, 1868. After studying at Owens College, Manchester, he was engaged during 1888 and 1889 in his father's

cotton mills, and in extending, by private reading and tuition, his knowledge of the theory of engineering. In 1890 he took the third year's course in engineering under Professor Unwin at the Central Institution of the City and Guilds of London Institute, and in 1891 he entered the works of Messrs. Yarrow and Company at Poplar. While there his health broke down, and he had to give up work for a time. In 1893 he was able to carry out the refitting and re-organization of the repairing shop at Messrs. Thomasson and Son's factory, and to superintend the introduction of various machinery, but owing to continued ill-health he was from that time not in a position to undertake regular work. He died on the 3rd October, 1898, at Hawkshead House, Hatfield. Mr. Thomasson was elected an Associate Member on the 2nd May, 1893.

*** The following deaths have also been made known since the 6th October, 1898:—

Members.

CUNNINGHAM, JAMES; *died* 4 December, 1898.

CLARK, LATIMER; *died* 30 October, 1898.

HENDERSON, WILLIAM; *died* 11 December, 1898.

MCCURRICH, JOHN MARTIN, M.A.; *died* 18 January, 1899.

PARKER, WILLIAM; *died* October, 1898.

SCALDWELL, ROBERT THOMAS; *died* 21 September, 1898.

Associate Members.

CUMING, JAMES HENING, F.C.H.; *died* November, 1898.

MICHELL, WILLIAM; *died* 12 January, 1899.

PEACE, ALFRED LINDLEY; *died* 26 November, 1898.

STOKES, JAMES FOLLIOTT; *died* 6 January, 1899.

WHITE, JOHN; *died* 22 October, 1898.

WIGAN, LEONARD; *died* 9 December, 1898.

WILLIAMS, HUGH; *died* 9 December, 1898.

Associates.

BAYLISS, SAMUEL; *died* 27 November, 1898.

SWARBRICK, SAMUEL; *died* 22 January, 1899.

Information as to the career and characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 14 February, 1899.

Sect. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

The Tensile Strength of Stone-like Bodies. A. Föpple.

(Centralblatt der Bauverwaltung, 1898, pp. 268-274.)

After referring to accounts of his earlier experiments,[1] the Author describes the following endeavour to obtain by direct means the true tensile strength of cement.

The test-pieces were of neat cement of the usual double-wedge-shaped form, mixed by weight with 54 parts of water to 200 parts of cement. In the end of each test-piece were embedded two pieces of wire rope 3 millimetres (0·118 inch) in diameter, composed of thirty-six strands; the free ends of the pieces of rope were formed into loops and the embedded ends splayed out like brushes so as to be gripped by the cement. The wires reached on either side to within 1 centimetre (0·39 inch) of the centre of the test-piece.

Five series of twenty test-pieces were broken; half in the usual way by jaws holding the specimen, the rope being cut off short and left slightly projecting; and half, in the same machine, by means of pulls applied by hooks to the rope loops. The following Table gives the results of the experiments in kilograms per square centimetre; and as the figures are only useful in comparison with each other they have not been converted to English measure:—

Remarks.	Age.				
	3 Days.	7 Days.		28 Days.	
		First Series.	Second Series.	First Series.	Second Series.
Broken with jaws . .	22·86	28·44	22·80	35·71	33·84
„ „ rope . .	24·95	31·95	28·47	44·19	40·07
Difference per cent. . .	9·3	12·4	26·1	23·7	18·4

It is not claimed that by the use of the wire rope inequality of stress on the specimen is eliminated, but only that it is decreased.

W. B.

[1] Thonindustriezeitung, 1896, p. 145; Centralblatt der Bauverwaltung, 1897, p. 6.

Standard Sand for Cement-Testing. GARY.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1898, p. 121.)

In Prussia a standard sand for cement-testing has been adopted, but in no other country. The adoption of an international standard sand is desirable, so that, in testing mixtures of sand and cement, the influence of the varying properties of sand might be eliminated.

The Author obtained samples of the sands used in various countries for cement-testing, and made test specimens of 1 cement 3 sand, and 1 cement 5 sand. The sands were obtained from Prussia, the Rhine, Austria, Switzerland, Russia, Norway, France, England and America. They were carefully examined as to specific weight, size of grain, chemical composition, and strength in tension and compression when mixed with Portland cement. The specimens were tested at the ages of 7 days, 28 days, and 90 days. The strengths of the specimens made from the different sands differ considerably, as is to be expected from the different physical properties of the sand; the difference is most marked in compressive tests. The sands with sharp angular grains are strong in tension; those with round grains strong in compression.

The Paper is accompanied by numerous tables, diagrams, and sheets of microphotographic reproductions, showing the sand particles.

A. S.

The "Le Chatelier" Volumometer. C. PIENO.

(Annales des Travaux publics de Belgique, 1898, p. 453.)

For some years one of the clauses in French cement specifications has read as follows, "poured slowly into a measure and not heaped up, the cement shall weigh not less than 103 lbs. per bushel." The Author states that the weight per bushel was, for a long time, thought to indicate whether the cement had been properly burnt, and not much account was taken of the fineness of the grinding. He then shows that it is impossible to draw any conclusions as to the extent to which the cement has been burnt from the weight per bushel; but from the specific weight it can be ascertained whether foreign substances have been added, by comparing the density with the known mean density of Portland cement, viz., 3·10.

In order to determine the density, the apparatus most commonly in use on the Continent is the volumometer of Schumann, an illustration and description of which is given. The Author, however, considers it defective in several points, and proceeds to describe an improved volumometer, the invention of Le Chatelier.

It consists of a phial having a capacity of about 120 cubic centimetres (7·32 cubic inches), with a narrow neck about 20 centimetres (7·87 inches) in length. Towards the top of the neck a bulb is formed having a capacity of about 20 cubic centimetres (1·22 cubic inch), a line graven in the glass above and below the bulb exactly marking this capacity. Above the top line the neck is graduated 0 to 3 cubic centimetres in tenths. The diameter of the neck is about 0·01 millimetre (0·39 inch), and the length of neck from the phial to the bulb about 0·10 metre (3·93 inches).

To determine the density of the cement, the apparatus is filled with benzine up to the lower line, and 64 grams (0·1408 lb.) of cement carefully weighed, and poured in little by little. When the benzine rises to the upper line the remainder of the cement is weighed, and the amount subtracted from 64 grams, the difference will represent the weight contained in 20 cubic centimetres (1·22 cubic inch).

After describing another method of determining the density, and mentioning various precautions to be observed in the use of the apparatus, the Author summarizes its advantages, and states that for exactitude, simplicity, and ease in operating, it has no equal.

H. I. J.

Test of a Wire Rope 3½ inches in Diameter. A. Martens.

(Mittheilungen aus den königlichen technischen Versuchsanstalten zu Berlin, 1898, p. 89.)

A wire rope 90 millimetres outside diameter was tested at the Royal Testing Laboratory. The rope consisted of six principal strands and a central core. Each principal strand consisted of six secondary strands and a hemp core, while the secondary strands each contained thirty wires in two layers of eighteen and twelve round a hemp core. The rope therefore contained $6 \times 6 \times 30 = 1{,}080$ wires, each 1·46 millimetre (0·058 inch) diameter. The tensile strength of the wire was 116 tons per square inch, and if the full strength of the individual wires had been obtained, the rope should have had a breaking strength of 330 tons. The rope was bent round two special castings which were attached to the testing machine. One end of the rope was lashed by three pairs of screw clamps, each with eight bolts 2½ inches diameter; the other end was spliced. Great difficulty was experienced with the clamp fastenings, owing to the contraction of the rope as the load increased. The circumference was 288 millimetres before the application of the first load, and shrank to 252 millimetres with 150 tons load. The rope ultimately broke near the end of the splice with a load of about 250 tons, giving a coefficient of strength 0·75.

A. S.

Experiments on the Emission of Air through Divergent Conical Nozzles. A. FLIEGNER.

(Schweizerische Bauzeitung, 1898, p. 68 *et seq.* 14 Figs.)

The experiments described in this article were suggested by a consideration of the construction of the De Laval steam-turbine. In this apparatus a special nozzle is used, consisting of a taper-pipe, with the sharp entrance edge rounded off and the outlet end made parallel for a certain distance. In certain published accounts of the turbine it had been stated that a nozzle of the described form caused a reduction in the pressure of steam from that in the pipe to that in the turbine chamber, and that the steam issued from it in the form of a well-defined jet. It was also stated, that in this way the velocity of the jet reached 3,280 feet per second, while with a well-rounded edge the velocity attained was barely half as great. Nothing was stated, however, as to the method of experiment adopted, and the Author believes it was taken for granted that adiabatic expansion occurred. He considered the conclusions doubtful, and decided to make special tests, but being unable to use steam he experimented with air, using the air-pressure apparatus at the Zurich Polytechnic. Two precisely similar nozzles were used. The inlet end was rounded and the nozzle was first bored out parallel and then more and more conical, and tests made after each operation. A piece 3·94 inches long next the inlet was left parallel, but no parallel outlet was left, as in the De Laval nozzle, as it was difficult to arrange, and the Author considered it had no effect. In the tables of results the diameter of the emission end only is given. The pressure was measured at three places in the length through orifices 1 millimetre (0·039 inch) diameter. After a detailed description of his method of experimenting, the Author gives a series of elaborate curves and tables, and in conclusion points out that his doubts proved well founded. The average pressure in the plane of the outlet of the nozzle never sinks to that of the surrounding pressure.

The statement that adiabatic expansion takes place is also incorrect. In the case of elastic fluids an increase in the cross-section of the nozzle causes an increase of resistance; if then it be desired to produce the greatest possible emission velocity, the cross-section must be increased as little as possible, just as is the case with dripping tubes. The same laws apply to steam, and the Author concludes, that with the present boiler pressures, an emission velocity of 3,280 feet per second is absolutely impossible.

E. R. D.

Experiments on a Flexible Joint for Riveted Framing.

MESNAGER.

(Annales des Ponts et Chaussées, 1898, p. 300.)

The Author points out that in tests made on a large number of bridges on the French railways it has been found that the secondary strains frequently attain to 25 per cent. to 30 per cent. of the principal strains. In a previous Paper[1] he proposed an arrangement of jointing for lattice girders which would reduce to a negligible quantity these secondary strains, and in the present Paper he describes some experiments made upon a bridge-panel or bay, built upon this system, of the largest dimensions which could be tested in the laboratory of the School of Bridges and Roads.

This experimental panel, measuring 9 feet 6 inches in height by 11 feet 7 inches in length, corresponded to a portion of a girder of an 82-foot-span bridge, and was subjected to a series of tests, which were carried up to breaking-point. A Plate with three Figs. gives full dimensions of the members of the girder and their arrangement. The secondary members of the girder are formed of a plate stiffened by angle-bars, which are cut off short of the point of junction with the main girder at a distance about fifteen times the thickness of the plate, which plate is continued on and riveted to the main girder, the free portion of the plate forming the flexible joint.

The panel was tested on its side, *i.e.*, with the uprights horizontal, and the pressure transmitted from the four jaws of the machine through horizontal knife-edges. Arrangements were also made by which a bending strain and also an angular pressure could be put upon the panel, both of which corresponded to the pressure which would be taken by a bridge under ordinary conditions of working.

By means of two telescopes fixed upon one of the main uprights as close as possible to the centre line of the panel, readings could be taken on a scale fixed on the other upright, and the least angular deformation could easily be read.

A Table gives full details of each experiment, from which the following deductions are made:—

In order to have the maximum resistance it is necessary—

(1) To use a plate the whole width of the joint, and not two plates joined together.

(2) To stiffen by transverse angle-bars up to the limit of the free part of the joint.

(3) To bring the rivets joining the flexible plate to the main girder, as close to the edge as possible.

Since making these experiments a bridge of 131 feet span, to be

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[1] Annales des Ponts et Chaussées, 1896, part 2, p. 750.

constructed on the principles described, has been approved by the Minister of Public Works, and the details of the design are shown in seven Figs.

The Paper is illustrated by Figs. in the text and three Plates.

H. I. J.

The Use of Jointed Members in Roof-Construction.

A. KIELBASINSKI.

(Schweizerische Bauzeitung, 1898, p. 38. 7 Figs.)

In the machine building of the Geneva Exhibition of 1896 a little-known type of roof-construction was used, which depends upon the principle of jointed members, such as have long been in use in bridge-work. Professor Jules Gaudard in 1896 published, in "Le Génie Civil," an account of this type of roof, with calculations, and he states that it was first used at the Chicago Exhibition. The Author points out, however, that the construction has been used in St. Petersburg since 1892, and was employed for the first time by Professor Jasinski for the new locomotive shops of the Nikolai Railway and for other buildings since that time. The Author shortly states the principle, and then illustrates it by sketches of a roof covering a building, 133 feet wide, divided into three bays by two rows of columns, the two side bays being each 43·3 feet wide and the centre bay 46·4 feet wide. The framework of the roof consisted of two independent triangular systems with a triangular system forming the apex of the roof resting upon the free ends of both side systems. The principals were placed at 10·3 feet centres, and the ends of alternate principals were supported upon the stanchions. The columns were set 20·6 feet apart in a longitudinal direction. The triangular framework at the apex of the roof forms the lantern and rests upon the ends of the side systems. In the system as first designed the lantern part was a rigid three-cornered frame, but now it is made of linkwork. The advantages of the latter arrangement are: (1) that the weight of the lantern frame produces a horizontal thrust on the side members in the opposite sense to that produced by the horizontal component of the wind-pressure; (2) by this system alone is it possible to distribute the wind-pressure on to both side walls through the principal rafters. Details of construction are shown in the figures.

E. R. D.

Reconstruction of the Railway Bridge over the Rhine at Düsseldorf. Platt.

(Centralblatt der Bauverwaltung, 1898, pp. 351 *et seq.*)

The bridge has a total length of 815·33 metres (2,674 feet), including four stream spans of 103·57 metres (340 feet), and carries a double track of railway. The river spans are crossed by girders, while the approaches are carried on brick arches 18·83 metres (61·8 feet) span. In 1895–96 it was decided to reconstruct the deck of the river bridge and to renew the covering and filling in of the arches, which had become leaky and sodden.

About seventy-three passenger and goods trains pass the bridge daily, and the plan adopted for reconstruction necessitated working the length over the bridge as a single line. The Author gives the regulations enforced for the safety of the traffic, and a diagram of the special signalling arrangements, &c.

On the arched part of the bridge the old filling in and asphalt was removed, and new asphalt laid down and covered with 5 centimetres (2 inches) of clean sand. Three small drain-pipes were laid longitudinally along the centre of the bridge embedded in the sand. A layer of bricks on the flat with open joints was placed on the sand, over this dry stone packing, and finally a depth of 40 centimetres (1·3 foot) of ballast.

While the bed of one pair of rails was relaid, that of the pair in use was supported by short timber struts from the side walls, which are very solidly constructed.

Prices in some detail are given, also five illustrations.

W. B.

The Kornhaus Bridge at Berne. P. Simons.

(Schweizerische Bauzeitung, 1898, p. 92. 12 Figs.)

Allusion was made to this bridge in the Minutes of Proceedings, vol. cxxxiv., and in the present Paper full details are given of the difficulties overcome. Considerable trouble was experienced with the foundations of the pier on the right bank of the river. Before the contract was let a series of bore-holes was made at about equal distances along the centre line of the proposed bridge. One of the bore-holes was in the centre of the site of the proposed pier on the right bank and a bed of clay was found at a depth of 37 feet. It was decided to make this the foundation and provide an air-pressure of 75 lbs. per square inch. As troubles with ground-water were expected, a sum of £800 was put aside to provide for pumping. In July, 1895, the work was begun, and instead of pumping it was decided to use sheet piling of steel of I section. This method was

employed quite satisfactorily on the left bank of the river, the points of the piles being driven 9·85 feet below the bottom of the foundation. As soon as work was begun and the slope of the Altenberg was cut into, it was found that the site was very different from what was anticipated. It was found that the bed of clay had a sharp dip across the axis of the bridge; water was also encountered, and it was found that an underground lake of considerable extent had been tapped; the water was eventually led off by two siphons. The quality of the ground was found to be so bad that the pier could not be built as originally intended, and other bore-holes, carried 85 feet below the proposed foundation-level, showed even worse results. Experts were called in, who decided that it was necessary to increase the area of the foundation 9·85 feet in each direction, and the site was to be surrounded with sheet piling and the whole area filled with pitch-pine piles, 40 feet to 50 feet long, which were to be driven by a steam pile-driver weighing 1,760 lbs. to 2,200 lbs. The Author gives details of the manner in which the work was carried out. The I-piling previously put in was removed with dynamite. The pitch-pine piles were from 12·6 inches to 15 inches square, and these were driven until a series of 10 blows with a ram weighing 2,200 lbs. drove the pile only 2 inches. Laying of the concrete foundation could only be begun on the 18th February, 1897; the concrete consisted of 440 lbs. of cement to 8 cubic feet of sand and 20·5 cubic feet of stone. This pier after completion only sank 0·39 inch.

E. R. D.

Arch Bridge over Schuylkill River, Fairmount Park, Philadelphia.

(Engineering News, New York, 4 August, 1898, p. 67.)

There are four arch spans of 208 feet, and some smaller girder-spans on each side, making a total length of 1,097 feet. Three arches, side by side, 28 feet apart support the platform, 79 feet wide, of which a concrete footway occupies 12 feet, a concrete carriage-way 40 feet, and a double electric railway 27 feet. The arches are constructed on three hinges, with vertical posts and diagonals between arch and horizontal top member. Posts, diagonals and top members are made of two channel irons braced together, but as the channels are turned outward, the bracing stops at the assembling plates. Transverse bracing is placed between the arch members and the vertical posts. All connections are riveted. The bridge was designed and erected by the Phœnix Bridge Company. The article is fully illustrated.

M. A. E.

The Vierendeel Bridge.

Report by A. Lambin and P. Christophe.

(Bulletin of the International Railway Congress, October 1898, p. 1159.)

The bridge, 103 feet 6 inches span, designed for the Brussels Exhibition of 1896 by Professor Vierendeel of the Louvain University according to his new system, has girders with parallel flanges and verticals in the web but no diagonals, the corners of the rectangular panels being rounded and strengthened by an inner flange.[1] It was tested to destruction in November, 1897, and this report was made at the instance of the Ministry of Public Works. It begins by setting forth the advantages claimed by the inventor, which are mainly as follows:—

That the practical method of calculating stresses by assuming pivots in the booms in the centre of each panel is more accurate than that by assuming in a lattice girder pivots at the ends of each diagonal and vertical, and that the accurate method, based in both cases upon the assumption of the invariability of the angles formed by the members with each other at their junction, is simpler in the case of the new girder; that the deflection of the new girder is less; that it is more capable of withstanding blows and vibrations and less liable to rust; that therefore higher working stresses may be applied than in a lattice girder; that the new girder can be more easily and accurately put together, and that it is lighter and less costly.

The tests made with numerous apparatus for measuring deflections and variations of lengths are explained by calculations, tables of measurements and photographic views. The latter show that the weakest point was in the panel nearest to one of the supports; the web in the rounded corners lying in the direction of the missing diagonal tie was buckled laterally, and the web in the two other corners torn in more than one direction, as was expected; the right angles between the booms and the verticals had been altered. Measurements of variations of lengths and observations of the effect of temperature lead the reporters to the conclusion that the alteration of the right angles showed signs of developing as soon as the operation of loading commenced (p. 1226), certainly previous to the limit of elasticity being reached according to the calculation. This would contradict the admissibility of the assumption on which the accurate calculation is based. Hence the degree of accuracy in the calculation of the new girder is of the same order as that of lattice bridges, and higher working stresses are not admissible. On these conditions the weight would

[1] The great girder bridge over the River Wear at Sunderland belongs to this type; but as the girders are of the bowstring form the diagonal stresses in the web are comparatively insignificant, and not so much attention need be given to the construction of the rounded corners.—M. A. E.

not be less, but the difference is unimportant even if certain recommendations for strengthening the connections are followed. According to statements by manufacturers it appears that the cost would be slightly greater. In conclusion, so far as matters stand at present, the new girder is neither better nor worse than the lattice girder.

M. A. E.

Bridge Work on the Kansas City, Pittsburg and Gulf Railroad.

(Engineering News, New York, 25 August, 1898, p. 114.)

The 50-foot and 60-foot spans are plate-girders. The truss of the 100-foot span is formed as a triangle, of 100 feet base and 40 feet height; it has four sub-divisions, so that the cross-girders are 25 feet apart. The connections are by pins. The 127-foot and 150-foot trusses of the riveted type, all struts being made of two channel-bars, the channels of posts and diagonals being turned inwards. The depth of the 150-foot truss is 28 feet, and the panel length 25 feet. The trusses are 17 feet apart. The 200-foot trusses are pin-connected. The 100-foot and 150-foot trusses are fully illustrated. The longest bridge on the line, the Arkansas River bridge, consists of a through span of 250 feet and eight deck spans 130 feet to 150 feet long, making a total length of 1,470 feet. The construction of the concrete piers is fully described by a reprint of the engineer's report.

M. A. E.

Bridge Disaster at Cornwall, Ontario.

(Engineering News, New York, 15 September, 1898, p. 274.)

Two of the three 368-feet span Pratt trusses, under construction for carrying the single line of the New York and Ottawa Railway over the St. Lawrence River, collapsed on the 6th September, 1898. The shore span, still supported on scaffolding, was fixed to the masonry pier, while the second span, without scaffolding, rested on rollers. The pier completely disappeared under the water. These circumstances led the writer to the conclusion that the girders were not at fault, but that the collapse was caused by undermining of the foundations by the current which runs from 5 to 8 miles per hour. The river is 35 feet deep; a timber crib, 18 feet by 62 feet and 35 feet high, had been sunk with some difficulty, and only after this had been done the ground could be examined by divers. Hard boulder clay being found, 50 cubic yards of concrete were deposited in bags and the remainder lowered in buckets of 1 cubic yard. When a level 4 feet under water was reached, work was stopped for the winter; then the crib was pumped dry and

masonry built to 35 feet above the water-level. This gives a height of 70 feet on the narrow base of 18 feet, and, moreover, as shown by a photograph, the pier was built out of centre to correct inaccuracy in sinking the crib. This, combined with the increased current through obstruction by the scaffold piles, seems to account for scouring under the pier as the cause of the disaster, causing the loss of fifteen lives and serious injury to sixteen men.

M. A. E.

Hygienic Regulations for Workers in Compressed Air.

L. Brennecke.

(Centralblatt der Bauverwaltung, 1898, p. 305.)

Following upon an earlier article,[1] the Author gives in full thirty-six rules drawn up by Drs. Richard Heller, Wilhelm, Mayer, and Hermann v. Schrötter, for the regulation of workers in compressed air, and embodying the results of a long series of experiments conducted by them.

Among other points, it is stated that work can be carried on in pressures up to five atmospheres. The following Tables give the least times which should be taken in "locking" workmen in and out of compressed air :—

"Locking" in—

0·5	atmosphere,	not	less	than	5	minutes.
1·5	,,	,,	,,	,,	10	,,
2·5	atmospheres, ,,	,,	,,	,,	15	,,
3·5	,,	,,	,,	,,	20	,,
..	. . .	. .	. .	. .	..	
..	. . .	. .	. .	. .	..	
5·0	,,	,,	,,	,,	30	,,

"Locking" out—

0·5	atmosphere,	not	less	than	10	minutes.
1·0	,,	,,	,,	,,	20	,,
1·5	,,	,,	,,	,,	30	,,
2·0	atmospheres	,,	,,	,,	40	,,
2·5	,,	,,	,,	,,	50	,,
3·0	,,	,,	,,	,,	60	,,
3·5	,,	,,	,,	,,	70	,,
..	. . .	. .	. .	. .	..	
..	. . .	. .	. .	. .	..	
5·0	,,	,,	,,	,,	100	,,

In all cases, the reduction of each 0·1 atmosphere pressure should occupy at least 2 minutes.

W. B.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxxi. p. 398.

Moving Bodily an Iron Roof of 98-feet Span.

A. DA CUNHA.

(La Nature, 26 November, 1898, p. 403.)

In the course of the demolitions in the Champ de Mars for the Paris Exhibition of 1900, it has been necessary to pull down the former machine-gallery, which had a width of 98 feet, and which had been left standing at the close of the last Exhibition. After the masonry of the side walls was removed, it was decided to employ part of the roofing for the New Electrical Buildings, which will occupy a position at right angles to the original machine-gallery. The simplest mode of making use of the old roof-trusses was to shift them in their entirety, and although this operation is not a novel one, it entailed in the present instance some peculiar features. By reference to a plan the Author describes the three stages in the work; a forward movement for a certain distance, a rotation through an arc of 90°, and a farther movement at right angles to the former one. The gallery it was intended to remove was divided into three sections, each comprising one bay of two complete trusses, with all the intermediate purlins and transoms. Each of these divisions was dealt with independently. In order to brace together each section, and to stiffen it for the removal, the feet of the four main stanchions were united by means of temporary lattice girders 3 feet 3 inches in depth formed of tee-iron, supplemented by vertical and cross ties of steel cable, and the complete structure was lifted from its base, supported on a staging of squared timber, and finally placed on small trucks running on rails beneath each of the four upright stanchions. Each truck moved on four small rollers placed one behind the other, and the whole weight of the structure (about 140 tons) was thus distributed over the sixteen rollers. It was easy to propel the load in a straight line, but special provisions had to be made to rotate the mass so as to assume the new direction needed. The mode of doing this by constructing the platform of each truck in such a way as to allow the weight to revolve on a central pin is described by reference to illustrations. The removal was contracted for by weight; the price, at 4*s.* per cwt., amounting to £1,720.

G. R. R.

Two Coal-Storage Buildings at West Superior, Wis., U.S.

(Engineering News, New York, 18 August, 1898, p. 99.)

These are dome-shaped structures, 246 feet diameter, and 100 feet high. Twenty-four arched ribs, with a tubular top member and a single-webbed bottom member, spring from the ground on hinges. A group of three ribs from one side, joined

together near the top, meets a similar group from the other side in one hinge, and the four hinges thus required are independent of each other at different levels in the central vertical. The covering is corrugated iron down to 20 feet above ground and a vertical corrugated iron wall extends from the ground to nearly that height. To resist the pressure of the coal the wall is tied to a steel band about 200 feet diameter, which is buried under the coal when the building is filled. The filling takes place by means of endless-chain conveyors, fitted to a straight trimmer-trough ascending from the outside ground over the corrugated iron wall and inside the building to its apex. The bottom of the trough is formed by a movable steel band, and the opening can be placed gradually higher so that the cone of coal is formed without the coal falling deep. The emptying takes place through a radial tunnel under the floor, containing an endless-chain conveyor, which is served by a reloader. This consists of a system of pockets moving on an endless chain close above the ground from the wall to the centre of the building, and, being pivoted here, can take coal from any part of the pile to the end of the tunnel in the centre. At first the reloader lies over the tunnel buried under the coal, and till it is free the tunnel must be served by shoots suitably placed on each side of it.

M. A. E.

Steel Dome for the Yerkes Observatory, Lake Geneva, Wis.

(Engineering News, New York, 14 July, 1898, p. 18.)

The building has a diameter of 90 feet and a height of 60 feet covering the Yerkes telescope, which has an object glass 40 inches in diameter. The dome is made to revolve on a circular rail by means of an endless rope driven by electricity or by hand. It consists mainly of two parallel ribs at a distance of 12 feet. The greater part of this space is not braced across, as between zenith and horizon it forms the observing opening; their horizontal thrust is taken by a heavy lattice ring to which the twenty-two wheels are fixed. Eighteen secondary ribs are placed between the ring and the main ribs, and serve to brace the structure and to form the supporting structure of the roof covering. The observing opening can be closed by two curved shutters moving on horizontal straight rails, one being fixed to the lattice ring, and the other to the main ribs 6 feet beyond the zenith. The floor round the pier of the telescope can be raised or lowered that the eye-piece of the telescope may be accessible at all positions. The article is illustrated.

M. A. E.

The Ports and the Maritime Canal of Bruges. GEORGES LEUGNY.

(La Revue Technique, 25 September, 1898, p. 413.)

During the Middle Ages Bruges possessed one of the principal ports of the North of Europe. At that time the Flemish borders were in communication with the sea by means of the Swyn estuary. Unfortunately for the prosperity of the city the bay gradually became filled up with sand, and the citizens had to remove their port, first to Damme and subsequently to L'Ecluse. In the fifteenth century they had to abandon the Gulf of Swyn altogether, and a semi-maritime canal was constructed later to Ostend; the depth, at first only 6 feet 6 inches, was subsequently increased to 14 feet 9 inches; but the town never regained its former prosperity. In 1877 it was proposed to construct a ship canal directly to the sea, but the plan was only settled on its present basis in 1879. The law passed in September, 1895, approved of the entire project, which embraces the creation of a port of call on the coast near Heyst [1] for large vessels, placed in communication with an inner harbour at Bruges by means of a deep and wide maritime canal. The execution of the scheme was, on the 10th January, 1896, entrusted to a company, and the contractors, Messrs. L. Coiseau and J. Cousin, have undertaken to complete the works by September, 1902, for the sum of £1,558,000. The sea-wall enclosing the outer harbour will start from the coast between Blankenberghe and Heyst; its plan is curvilinear, composed of two arcs of circles, the one having a radius of 1,311 yards and the other of 2,187 yards. The total length is 2,250 yards, but the first 335 yards of the superstructure, starting from low-water mark, will rest upon open steel piling, in order that the tidal scour may carry away the silt from the harbour. The remainder of the sea-wall will be founded upon monolithic concrete blocks weighing from 2,500 tons to 3,000 tons each. Details are given respecting the construction of the pier, the entrance channel, the locks, &c., and the inner harbour. The maritime canal, which starts immediately behind the locks, in the same line as the approach channel, is 6·21 miles in length, with a depth of 26 feet 3 inches. The interior port will comprise two basins—the east basin, 26 feet 3 inches in depth, and the western and larger basin, having a depth of only 21 feet 4 inches. Details are given of the present state of the works, and the general arrangement of the scheme is shown by sketch plans. The company has obtained the concession for a period of 75 years.

G. R. R.

[1] Minutes of Proceedings Inst. C.E., vol. cxxix. p. 414.

Sea-Coast Protection Works in Holland. Von Horn.

(Centralblatt der Bauverwaltung, 1898, p. 339.)

Cross sections are given of the works at Hondsbossche-Pettem which have a length of 5,520 metres (3·4 miles). The embankment rises to a height of + 6 to + 7 metres (19·7 feet to 23·0 feet) above high water, and the slopes vary from 40 : 1 to 2 : 1; it is composed of clay partly protected by stone paving and strengthened by pilework at the foot. The works have cost about £275,000 since 1867.

Owing to the absence of fore-shore, the great depth of water near the coast line and the heavy sea prevalent, the outermost point of the island of Walcheen has been difficult to protect from the sea. The embankment, as now existing, has a length of 3½ kilometres (2·2 miles) and the cross section changes but slightly. Its height varies from + 4·50 to + 6·50 metres (14·8 feet to 21·3 feet) above high-water level and the chief slopes from 25 : 1 to 6 : 1. The toe of the bank is supported by sheet piling, and from low to above high-water mark the embankment is protected by stone paving resting on a layer of clay 1 metre (3·28 feet) thick. It is intended eventually to pave the whole surface. Above and below high-water mark piles driven into the bank at intervals and braced together longitudinally and transversely serve as wave-breakers. These piles indeed break the waves, but also loosen the paving, and are therefore being gradually done away with. Five cross sections are given of this embankment.

W. B.

The Protection of Canal-Banks. Hippel.

(Centralblatt der Bauverwaltung, 1898, p. 294.)

The following method was employed to protect a length of bank on the Wentow Canal. From the bottom of the canal to the maximum water-level the bank has a slope of 1 to 1, and is protected by a continuous sheet of concrete, 20 centimetres (7·8 inches) thick, commencing at the foot of the bank and terminating in a horizontal ledge 0·75 metre (2·46 feet) wide. The depth of water is 2·54 metres (8·33 feet).

A network of round rods 6 millimetres (0·24 inch) in diameter with a mesh 0·25 metre (9·75 inches) square, is embedded in the centre of the concrete, and is secured by wire ties to two longitudinal flat bars and transverse flat bars every 3·5 metres (11·48 feet). The flat bars are laid on edge, and where they

cross are twisted so that they meet on the flat, and are riveted together.

The framework of flat bars is anchored back by four short screw anchors to every length of 3·5 metres, the distance between the transverse flats.

The method is not costly, and work can be done quickly; in the case described a length of 135 metres (443 feet) was built in eighteen days.

The article is illustrated by six cuts.

W. B.

Steel Dam for a Reservoir in Arizona, U.S.

(The Engineer, 12 August, 1898, p. 148.)

To secure a permanent supply of water on one division of its line in Arizona, the Atchison, Topeka and Santa Fe Railway has formed a reservoir by building a dam across Johnson's Cañon, capable of containing 40 million gallons. The dam is of steel with a concrete wall along its toe and a short abutment of concrete at each end. The steel portion is 190 feet long at the crest, with a maximum height of 40 feet; it is composed of a row of steel frames 8 feet apart, having a slope of 45° on the water face. The covering plates are steel, $\frac{3}{8}$ inch thick, about 16 feet long by 8 feet broad. The plates are dished to increase their resistance to the water-pressure.

A. W. B.

The Basic Company's Flume, Idaho U.S.

(Engineering and Mining Journal, vol. lxvi. p. 455.)

The Basic Company has installed a water-power plant on Grimes Creek to furnish, electrically, the power needed to work with dredges, extensive tracts of auriferous gravel. This necessitated the construction of a canal 43,868 feet in length, 15,765 feet being ditch, and 28,102 feet being flume. Of the latter, 1,977 feet are on trestlework, and 163½ feet are in a tunnel. The ditch is of uniform dimensions throughout, having a width at the bottom of 60 inches, at the top of 135 inches, and a depth of 36 inches. Its gradient is 5·28 feet to the mile. The flume is of two sections, the larger being 54 inches wide and 27 inches deep, and the smaller being 48 inches wide and 27 inches deep. The small section has a gradient of 10·56 feet to the mile, whilst the large section has the same gradient as the ditch. The tunnel is 5 feet wide at the bottom, 4 feet at the top, and 6½ feet high, these dimensions being inside the timbers. The trestles are all of single-deck work, the highest support being 25 feet, and the

uniform span being 12 feet. The work was completed in 121 days. The cost of excavation, including labour and materials, was 10*d.* per cubic yard. As the route was very heavily timbered, and so steep that surveying was in places a matter of considerable danger, this figure is believed to be unusually low. The total cost of the flume completed, excluding bridge and trestlework carrying it over ravines, was 3*s.* 7*d.* per lineal foot. From the pressure-box, at the end of the canal, the water is conducted through a steel pipe 730 feet in length, having a diameter at first of 26 inches, coming down gradually to 22 inches, thence through a short reducer of 15 inches, and a cast-iron nozzle in two jets to the Pelton water-wheel in the power-house. The total effective head is 347 feet. The capacity of the canal corresponds to the delivery at the pressure-box of 40 cubic feet of water per second.

B. H. B.

The Significance of Subsoil Water. E. Prinz.

(Gesundheits-Ingenieur, 15 October, 1898, p. 320.)

Attempts have been made to estimate the total volume of water on the surface of the globe, and some figures are given to show the amount which falls annually in the shape of rain, etc., and the volume which passes into the ocean by means of the various rivers. The residue is dispersed in the form of vapour, soaks into the ground, or is absorbed by vegetation. No computation is possible of the volume of water contained in the subsoil; but it is shown that certain watercourses are fed by underground supplies, and large fresh-water springs are known to issue beneath the sea, as, for instance, according to von Humboldt, in the vicinity of Cuba. The distance traversed by subsoil water may, in certain cases, be very considerable, and the rate of flow is generally infinitesimally small, as compared with streams flowing over the surface. Some soils furnish a natural filter-bed, through which the water may travel at the rate of from 10 feet to 16 feet per diem. These supplies can only be discovered and utilized by artificial means; but even in very ancient times, in Nineveh and in Egypt, recourse was had to sinking wells for water, and long before the Christian era the Chinese procured water by means of boring from a depth of upwards of 1,600 feet. The great caravan routes of antiquity depended upon the supply of water from wells, and the decay of Syria and Palestine is doubtless due to the failure to keep up the forests and the drying up of the water in the upper layers of the soil. Recently the subject of the utilization of the water in the subsoil has received an increasing amount of attention at the hands of engineers and those interested in public water-supplies.

G. R. R.

The Purification and Sterilization of Drinking-Water.

HENRI BERGÉ.

(Annales des Travaux publics de Belgique, 1898, p. 369.)

The Author points out that by reason of the increase of population, the multiplication of factories on the water-courses, and the increase of facilities of communication, (all of which tend to the spread of disease,) the difficulties of providing pure drinking-water are increasing every day. He shows that water is a fertile cause of the spread of diseases, more particularly diarrhœa, typhoid fever and cholera, and quotes the statement of Dr. Brouardel that since 1870 typhoid fever, propagated by impure water, has claimed more victims than the Franco-German war.

Pure water should present the following characteristics: An absence of smell, no taste, and a fresh and limpid appearance. Mineral elements in solution have only a relative importance, as also those containing some particular organic matters, *e.g.*, a water derived from turfy sources being perfectly wholesome, while another water charged with only a small quantity of organic matter containing microbes is unfit for drinking purposes.

Ideal drinking-water should contain no microbes, and systems of freezing, heating, mechanical filtration and filtration, aided by chemical agents have been proposed to lessen or destroy these microbes. Of these the Author, after careful examination, proves each system to be practically useless, in some instances the systems of mechanical filtration actually resulting in an increase in the number of microbes.

Since 1897 the Author, in conjunction with Albert Bergé and Emile Stein, has made important experiments with a little-known gas, viz., bioxide of chlorine, which has proved to have remarkable powers in sterilizing water. Its formula is ClO_2, and its preparation is very simple, consisting in decomposing chlorate of potash by sulphuric acid (64° Beaumé) at an ordinary temperature, the reaction, by the Author's method, presenting no danger. The gas is soluble in water, and decomposable by light, heat, or by contact with organic matter, upon which its effects are very rapid.

The Author describes experiments made on various waters, showing the absolute sterilization produced by this gas, and concludes by giving particulars of various ways in which practical use can be made of the discovery in acting upon large bodies of water.

An appendix gives extracts from various sources detailing the effects which impure water has caused in various towns, in the dissemination of diseases.

H. I. J.

The Plymouth Water-Supply.

(The Engineer, 23 September, 1898, p. 301 *et seq.*)

The large storage reservoir just completed, on Dartmoor, in connection with the water-supply of Plymouth, has been made by constructing a masonry dam across the bed of the Meavy, where it ran through a narrow channel known as Burrator Gorge. This dam rises to a height of 145 feet from its foundations and 77 feet above the bed of the river, the top-water level being 708·00 O.D. Its length is 410 feet, measured along the parapet, and its greatest thickness is 80 feet, diminishing to 20 feet at the top. The dam supports a roadway, five arches of 25 feet span carrying the latter over the portion of the crest of the dam forming the overflow weir. The faces of the dam are constructed of uncoursed ashlar, of squared blocks of granite, and the core of cyclopean rubble, consisting of large masses of granite embedded in concrete. On the water face the granite blocks are rebated to a depth of 6 inches, leaving a space $\frac{3}{4}$ inch wide, to that depth, between each of the blocks, which was filled with cement slightly damped and driven in by iron chisels.

The catchment area is 4,835 acres, and the average rainfall 65 inches. The length of the reservoir formed by the dam being $1\frac{3}{8}$ mile, with a maximum width of $\frac{1}{2}$ mile. It holds, when full, 650 million gallons.

A. W. B.

The Water-Carriage System in France. J. Stübben.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1898, p. 744.)

The Author directs attention to his recent communication[1] on the recommendations and conclusions framed by the Association of French House Proprietors. The views put forward on behalf of the Association by Mr. Badois have recently been considered by a Committee of the Société des Ingénieurs et Architectes Sanitaires de France, and Mr. Chardon reported to this latter Society in favour of the use of the Paris sewers for all liquid and solid dejections. He stated that while at the present time about half the sewage of Paris is diverted from the Seine, it is expected that by 1900 all the sewage will be intercepted and utilized on the land now being laid out for irrigation. He declared in favour of extending the area to be used for this purpose, in order to obtain, as far as may be possible, the full manurial value of the sewage water in the interests of agriculture. On the subject of the separate system of sewerage, he reported that this is only practicable in special cases, and that it is one certainly not adapted

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[1] Minutes of Proceedings Inst. C.E., vol. cxxxiv. p. 429.

for Paris. He asserted, moreover, that the adoption of this plan would not decrease the cost of sewage removal to house-owners. His report was adopted by the Committee with only one adverse vote (that of Mr. Badois), and it was resolved that the conclusions of the Third Congress of House-owners did not merit acceptance, and that the water-carriage system, decreed in accordance with the law of 10th July, 1894, should be maintained, and should be strictly enforced. It was further resolved that the price of water ought to be reduced, the supply of drinking-water increased, and that special provision should be made for the fullest possible use of the sewage-water for irrigation purposes. These resolutions were accepted unanimously by the general meeting of the Society on the 8th of May last, and the Author trusts that the completion of the Paris water-carriage system will now be effected without further interruption.

G. R. R.

The Removal of House-Refuse on the Kinsbruner System.

WALTHER HÄNTZSCHEL.

(Gesundheits-Ingenieur, 31 October, 1898, p. 329.)

It is shown that the first step in dealing with domestic refuse consists in the careful sorting of the same in order to collect the glass, metal, rags, leather, etc., which, when brought together, possess a considerable monetary value. The residue, which will consist largely of ashes, may then either be burnt or melted, this latter plan being adopted when the refuse is chiefly the ash of brown coal. Experiments recently conducted in Berlin go to prove that a temperature of about 1,800° C. is needed for this process, by which the ashes are converted into a black treacly mass, which it is proposed to utilize for the manufacture of paving blocks. The Berlin police regulations make it compulsory to collect the house-refuse without causing dust, and a company has been formed to introduce the Kinsbruner dust-preventing system of removal. By reference to illustrations the details of this plan are set forth. A van of a special type is employed, in which the dust is discharged into receptacles which tip over into the body of the van and are emptied so as to prevent any of the dust from escaping into the street. The entire body of the van can be lifted off the frame and wheels, in order to place the same on railway trucks or to discharge the contents into the holds of the vessels which ply on the River Spree. Special arrangements are also made to prevent any dust from escaping during the emptying or tipping process.

G. R. R.

The Disinfection of Dwellings by means of Formic Aldehyde.

Dr. Symanski.

(Zeitschrift für Hygiene, vol. xxviii., part 2, p. 219.)

Reference is made to the previous investigations of Aronson,[1] and to a series of thirteen sets of observations conducted partly by Prof. von Esmarch and partly by the Author at the Königsberg Hygienic Institute. The rooms in which these last tests were conducted are described, and an explanation is given by means of block plans of the position in the apartments of the various test objects, which consisted of different kinds of fabrics, strips of paper, silk threads, etc., infected with cultures of anthrax and bouillon-cultures of staphylococcus pyogenes aureus. In each case the doors and window-openings are shown in the plans, and also the situation of the spirit-lamp used to generate the gas. The effect upon the test-bacilli is set forth in a series of Tables, indicating those germs which were rendered incapable of further development. Some additional observations in a different room, in which an autoclave was substituted for the Schering lamp at first used, are also discussed. In these latter experiments, which were carried out by Dr. Dräer, the test-bacilli, consisting of bouillon-cultures of staphylococcus, cholera, typhoid fever, diphtheria, and anthrax, were placed upon pieces of linen, calico, flannel, woollen fabrics, silk and velvet; also on wood and glass, together with agar-cultures of certain of these germs. The results obtained are likewise shown in Tables. The Author examines the views expressed by various writers who have conducted observations of a similar kind, and formulates the whole series in a set of eight conclusions, which are briefly as follows:—(1) The disinfecting properties of the formic aldehyde gas evolved by means of the autoclave are superior to those of the vapours obtained by the use of the Schering apparatus; (2) by neither means is it possible to attain absolutely certain results; (3) the very favourable conclusions formed by certain of the previous observers were doubtless due to exceptionally advantageous circumstances; (4) the gaseous formic aldehyde possesses no penetrative powers; (5) these vapours are not injurious to fabrics, and only in a few cases affect colours and dyes; (6) the higher the temperature and the drier the atmosphere, the better are the results yielded in both cases; (7) the smell of the gas is frequently removed only with much difficulty, and lingers for days; (8) disinfection by this means is more costly and requires more time than by certain other processes commonly employed.

G. R. R.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxix. p. 428 *et seq.*

Increasing the Quantity of Ammonia in a Gaswork.

BRUNET.

(Proceedings of the Société Technique de l'Industrie du Gaz en France, 1898, p. 102.)

When tar is removed from the tanks, it will be found that it contains ammoniacal liquor in suspension in a minutely divided state. Various means have been tried to effect its separation from the tar, one of the most efficacious being a centrifugal apparatus; this is said to leave only 1 per cent. of liquor in the tar, but to effect this the tar must be warmed to render it sufficiently fluid. The ammoniacal water is generally, for the most part, lost, but it contains an appreciable amount of ammonia, and the Author has endeavoured to prevent this loss. Ammoniacal gas is very soluble in pure water, which will take up 1,000 volumes of the gas at 32° F. and 740 volumes at 59° F.

A laboratory experiment proves this fact in a striking manner. If a flask is filled with ammoniacal gas over mercury, and stopped with a cork, through which a small glass tube, closed at the exterior end, is passed, and if this end is broken under water, the water will be found to rush into the flask, filling it in a very short time. This experiment suggested the idea of removing, by one operation, the greater part of the ammonia suspended in the tar in the tanks. The plan consists simply in constantly maintaining a layer of water, at least 3 feet deep on the surface of the tar. By this means the ammoniacal gases are aspirated from the layer of tar next to the water, and each time that there is a movement in the mass of tar the pockets of liquor, large or small, tend to rise towards the surface, where the ammonia they contain becomes dissolved in the water above. To maintain a constant layer of clean water on the tar, it is sufficient to change the water so soon as it has a density of 1½° to 2° Beaumé. This plan has been used by the Author for 2 years, and he estimates that the quantity of water put into the tanks amounts to 132,129 gallons per annum, and the yield of ammonia has been successively increased from 4·10 to 4·36 and 4·83 lbs. per ton of coal carbonised, without the help of any special apparatus for collecting the ammonia, the gas being only washed in two ordinary coke scrubbers, one watered with weak ammoniacal liquor, and the other with clean water.

C. G.

Street-Lighting with Incandescent Gas-Burners in Munich.

DR. E. SCHILLING.

(Journal für Gasbeleuchtung, 1898, p. 397.)

Incandescent gas-burners are at present extensively used for both private and street lighting. In Munich they have been used for the latter purpose since October, 1897, there being at present 5,100 such burners fixed, all of which are provided with holophane glasses. The most frequented streets in Munich, especially in the old town, are lighted by electricity, and, in consequence of the increased light so obtained, it was found necessary to improve the gas-lighting in the other parts of the town. It was therefore decided to fit up the whole of the public gas-lamps with incandescent burners, and the conversion was completed by the 1st October, 1897, so that from that date to 1st April of this year, or for six months, the cost of working on a large scale, including maintenance, could be determined. The renewal of the mantles is an important item in the cost of maintenance, and the information available on this point varies considerably. In Munich the renewals of the chimneys has been at the rate of 2·011, and of the mantles at the rate of 4·2 per lamp per annum. A detailed estimate is given of the total cost, including all items, such as inspectors, fitters, labourers, workshop rent, repairs to burners, and interest and sinking funds on the original outlay. This amounts to 14*s.* 5*d.* per burner per annum, with the mantles costing 10·2*d.* each. The price of the mantles has since been reduced to 6*d.* per mantle, which reduces the cost of maintenance to 12*s.* 8*d.* per lamp per annum, but the town pays only 8*s.*

According to the annual report of the Munich Statistical Office for 1896, there were 830 electric arc-lamps in use in the city, which cost £22,795 for the year. The amount paid by the town for 5,100 incandescent gas-lamps is at the rate of £11,965 per annum, so that an electric arc-lamp costs £27 9*s.*, as compared with £2 7*s.* for an incandescent gas-lamp.

The experience in Munich is that, in streets where there is considerable traffic, the electric arc-lights are useful, but that the incandescent gas-lights are eminently adapted for general street lighting.

C. G.

The Methods of Estimating the Volume of Carbonic-Acid Gas.

GERDA TROILI-PETERSSON.

(Zeitschrift für Hygiene, 1898, p. 331.)

Reference is made to a previous communication on this subject [1] in which attention was directed to the mode of employing the Pettersson-Palmqvist apparatus, as modified by the Author, for experiments in regard to ventilation. Several varieties of similar apparatus, small in size and free from complex parts, have already been introduced, and exception is taken by the Author to the statement that the modified form of the above apparatus gave results which were inferior in point of accuracy to that described, for instance, by Bleier. It is shown that the figures relate not as assumed to percentages but to the parts per 1,000, and that while the greatest difference obtained between two estimations of the same sample of air by the use of the Author's portable apparatus was but 0·07 part per 1,000, the original form of the Pettersson and Palmqvist portable apparatus gave readings which might vary as much as 0·15 part per 1,000. Some later trials conducted by the Author with the two forms of portable apparatus are described, and in one case the air in a dwelling-room was found, after it had been occupied by one individual for 9 hours, to contain 0·82 part of carbonic-acid gas per 1,000 parts, the initial composition having been 0·65 part per 1,000. Some larger subsequent increases were suspected to be due to the escape into the room of the products of combustion in a close stove. In order to decide this point some tests were made with the stove by closing the valve, when the volume of carbonic-acid gas in the atmosphere of the room rose rapidly to 1·40 part per 1,000. Attention is directed to the errors likely to be caused in the use of all kinds of apparatus of this nature by variations in temperature, and some observations are given to illustrate this source of inaccuracy. For instance, a set of readings in two school-rooms are given in a Table showing the volume of carbonic-acid gas present at various short intervals, with the values obtained by the readings of different instruments. In these latter tests the opening of the windows between the lessons and the changes in the temperature induced great differences in the results.

G. R. R.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxxi. p. 476.

Acetylene Gas from the Hygienic Point of View.

JOSEPH VÉRTESS.

(Gesundheits-Ingenieur, 31 July, 1898, p. 225.)

The employment of acetylene is already becoming widespread, and while much has been written concerning its composition, its mode of production, and the burners best adapted for its combustion, little is known with respect to its influence upon health. These facts can conveniently be discussed under three heads:—(1) Acetylene gas when mingled with the atmosphere; (2) products of combustion in the case of acetylene, and (3) impurities in acetylene. It is pointed out that in consequence of the fact that calcium carbide is hygroscopic, this substance is liable to cause the spontaneous evolution of gas by gradually attracting moisture from the atmosphere. An American physician, Dr. Birchmoore, has maintained that even a volume of 0·01 per cent. of this gas in the atmosphere produces headache and sickness, but according to the Author this is a ridiculous exaggeration. Trouvé has asserted that this gas relieves colds and coughs. According to Gréhant even 20 per cent. of this gas in the atmosphere produces no evil effects, when breathed by animals, but with 40 per cent. the mixture was speedily fatal. The Author discusses the volume of gas absorbed by water, and calls attention to the fact that acetylene, when it constitutes one-twelfth part of the volume of air with which it is mingled yields an explosive mixture.

Under the second head, after a full consideration of the gases caused by burning pure acetylene, and after comparing them with those obtained by the combustion of common coal-gas, it is affirmed that acetylene under similar conditions, that is to say, with the production of an equal amount of light, vitiates less than one-half the volume of air that coal-gas does, and gives rise to far fewer products of combustion. An enumeration follows of the impurities likely to be present in acetylene; these are caused by certain substances found in the raw materials used in making the calcium carbide, and they consist mainly of phosphorus, sulphur, silicon and nitrogen compounds. The Author maintains that these substances, except perhaps phosphorus, cannot, with common care in the manufacture, exist in sufficient quantities to cause any ill effects to health.

G. R. R.

The Electricity Works of the Town of Schaffhausen.

K. P. TAÜBER.

(Schweizerische Bauzeitung, 1898, p. 167 *et seq.* 8 Figs.)

In the spring of 1895 the Town Council of Schaffhausen opened a competition for designs of an electricity works, and the plans of the Oerlikon Company for a single-phase alternating-plant were accepted. Work began in the spring of 1896, and in February, 1897, the works were taken over by the town. The energy is obtained from the turbines on the Rhine, installed in 1887–90 by the Water-Power Company; the plant is itself an extension of one put down 30 years ago for rope and shaft transmission of power to the district. In the new turbine house there are five Jonval turbines with vertical shafts by Escher, Wyss & Company. Each develops 300 HP. at 48 revolutions per minute; two are used to drive direct-current dynamos for the power-transmission to the Schaffhausen worsted-spinning mill, and two others for the electricity works now being described. Each turbine drives one dynamo through bevil wheels. Originally it was intended to fix a pulley on the shaft and drive the dynamo by ropes, but the more direct method was adopted. The possibility of placing the alternator direct on the vertical shaft was not overlooked, but the low speed and lack of space rendered it impracticable. The generators run at 167 revolutions, and give 100 amperes at 2,000 volts, with a periodicity of 50 per second, and they are of the Oerlikon inductor type. The exciter is a shunt wound machine giving 120 amperes at 50 volts, and 420 revolutions. Full details are given of the machines, and also of the switch-board. All the feeders are laid underground and are of the concentric lead-covered type, the potential is transformed down, and the secondary network in the town is all on the two-wire system and underground, while in the suburbs it is on the three-wire system, carried overhead. There are nineteen transformer stations of three types, the underground chamber, the iron chamber like a pillar letter-box, and a similar chamber with a lofty pole for the overhead wires. There are only two sizes of transformers, the 10-kilowatt and 20-kilowatt, and the primary current is transformed to 120 volts. The maximum output of the station at present is about 100 amperes at 2,110 volts, and it has been at work about 12 months.

E. R. D.

On the Wear of Steel Rails.[1]

(Report of the Società Italiana per le Strade ferrate meridionali: Rete Adriatica.)

The observations embodied in this report were made on six different types of rails, sections and dimensions of which are fully given in the text. The present normal type weighs from 72½ lbs. to 74½ lbs. per yard; but some sections are in use weighing 55½ lbs. and 42 lbs. per yard.

Apart from fractures, the life of rails varies very considerably on different lines and at different parts of the same lines; depending mainly upon the curves and gradients, on the traffic, and on the extent of exposure to atmospheric influence in tunnels or in open portions of the line.

The chief causes of failure of steel rails may be thus stated: (*a*) Fractures; (*b*) wear of the upper surface by the abrasive action of the wheels; (*c*) wear of the lower surface, chiefly by oxidising or corrosive agency; (*d*) deformation and wear of rails and fastenings at junctions of rail-lengths.

The most usual cause of fracture of a rail is some defect in the metal. From the 1st July, 1885, to the 31st December, 1896, the total number of fractures recorded on the company's lines was: between the 1st October and the 31st March, 529; between the 1st April and the 30th September, 265; *i.e.*, there were just twice as many fractures during the colder period as during the summer months.

The wear of the upper surface of the rail is, probably, the source of failure most readily assignable to known factors and definite rules. The statistics of this wear are scheduled in tabular form in the report; the following instances are selected from different lines, gradients, and positions quoted:—

Section of Line.	Gradient.	Radius.	Locality.	Total Wear of Rail-head.	Total Tonnage.
		Chains.		Inch.	Millions of Tons.
Foggia to Naples . . .	1 in 45·5	25	Open	0·071	11,318
„ „ . . .	1 „ 52·6	Straight	„	0·126	13,007
„ „ . . .	1 „ 66·7	„	Tunnel	0·292	23,205
„ „ . . .	1 „ 66·7	„	„	0·118	23,205
„ „ . . .	1 „ 62·5	„	„	0·118	12,761
„ „ . . .	1 „ 58·8	„	„	0·067	15,251
Naples to Eboli . . .	1 „ 47·6	26·5	„	0·331	18,151
„ „ . . .	1 „ 47·6	Straight	„	0·209	18,151

It is noted that the heaviest wear occurs near signals and

[1] Minutes of Proceedings Inst. C.E., vol. cxxx. p. 354.

stations, where the action of brakes is evident in the additional friction and abrasion.

A selection of summary results from various lines is quoted in the subjoined extract from the next series of Tables:—

Line.	Gradient.	Locality.	Total Tonnage.
			Millions of Tons.
Falconara to Ancona	Horizontal	Open	31,764
Orte to Foligno	1 in 133·5	,,	17,126
	1 ,, 45·5	,,	11,186
Foggia to Naples	1 ,, 47·6	,,	5,939
Bologna to Pistoia	1 ,, 40·0	,,	2,018
Orte to Foligno	1 ,, 66·7	Tunnel	2,868
Foggia to Naples	1 ,, 62·5	,,	5,150
Naples to Eboli	1 ,, 47·6	,,	2,432
Bologna to Pistoia	1 ,, 42·7	,,	2,028

The general conclusions to be deduced from these observations are: (1) That the wear of the upper surface of the rails increases rapidly with the increase of gradient; (2) that tunnels greatly influence the wear of the under surface of the rails, the rate of deterioration being about twice as rapid as where the rails are in the open.

This rapid deterioration, due to oxidising or corrosive action, is caused by the constant moisture in the tunnels, to the corrosive nature of the gaseous products of combustion, and to emanations from the soil. On account of these special causes of deterioration of the metal, the mere extent of abrasion in the head or top flange of the rail is an absolutely insufficient criterion for the determination of its life. Many rails, the wear of whose upper surface is still far from the maximum limit prescribed as necessitating renewal, have moments of resistance inferior to that of rails which have arrived at that limit. This conclusion is demonstrated by sections and particulars of rails from the Trabocco tunnel on the Bologna and Otranto line, and the Piteccio tunnel on the Bologna and Pistoia line.

A description is given of the Trochitomograph—an apparatus specially designed for delineating rail-sections. The frame, which is rigidly clamped on the rail, carries delicately but firmly adjusted equal and parallel arms on each side, with double points at each end. As one point traces the outline of the rail the other point necessarily follows absolutely every inequality, and records the outline on the paper secured on the frame.

The railway company has not made trial of any special varnishes or protective coverings for rails, not believing in their permanent utility, as they must necessarily get worn away at the surfaces of contact—precisely where most required. If, however, any coating is to be applied, it should be done directly the rails leave the rolling-mills.

The junctions of rail-ends constitute the weak point of permanent

way. The deflection and deformation of the rail-ends is often very marked, amounting in some cases to almost $\frac{1}{3}$ inch. Experiments have been made with the object of securing sufficient rigidity for the junctions, by bringing the end sleepers nearer together—from 24 inches to 20 inches apart—and by substituting an external check rail for the ordinary fish-plate. These have, however, not had a sufficiently lengthy trial to enable reliable results to be stated. It must be noted in this connection that where the gauge is eased, as on curves, the whole weight of the engine or carriage may, especially if the tires be unevenly worn, come upon the rail-end joint.

On the Florence and Pistoia line, with rails of the North Italian type, the end sleepers are spaced at $15\frac{3}{4}$ inches centre to centre. A rigid tongue with packing-rail stiffener has also been fitted; but it is cumbersome and complicated, and introduces liability to extra wear. A double-width sleeper ($17\frac{3}{4}$ inches) has been proposed, so as to take two chairs at $10\frac{1}{4}$ inches centres, constituting practically fixed ends, while leaving a sufficient degree of elasticity to the respective rails. These several methods of dealing with the case are illustrated and described in detail.

The following conclusions are stated as summarising the experience of the company as set forth in the report:—

(1) Fractures of rails are generally due to defects in the metal. The normal proportion of such failures is about 1 in 2,000 per annum. If above this rate, some abnormal conditions of quality or of local circumstances must be looked for.

(2) The wear of the upper surface of the rail is least where the line is open, straight or on easy curves and fairly level. The rate of wear increases rapidly in tunnels.

(3) The extent of wear alone is not sufficient to determine the presumptive life of a rail, as corrosive action must also be taken into consideration.

P. W. B.

The Railways of the World.

(Archiv für Post und Telegraphie, 1898, p. 470.)

This Paper gives an analysis of the present state of the railways in the world, with Tables showing the rate of development of the lines in the various countries and the ratios of length of line to the area of the country traversed and to the number of the population served.

One Table shows the length of railways on the five continents, from which it appears that in the year 1896 Europe had 159,723 miles, America 232,714 miles, Asia 28,493 miles, Africa 9,189 miles, and Australia 13,893 miles. The increase in length between the years 1893 and 1896 was lowest in America with 3·9 per cent., and greatest in Africa with 19·5 per cent. A detailed

Table follows, showing the distribution of railways in European countries, from which it appears that Norway was lowest with only 0·08 mile per square mile of territory, and Belgium the highest with 0·31 mile per square mile of territory, while the ratio of length to population was lowest in Servia with 1½ mile per 10,000 inhabitants, and highest in Sweden with 12½ miles per 10,000 inhabitants.

E. R. D.

Extension of the Paris Eastern Railway Station. A. DA CUNHA.

(La Nature, 5 November, 1898, p. 358.)

Nearly all the great railway companies which have their termini in Paris are making special preparations for the Exhibition of 1900. In addition to its main line traffic, the Eastern Railway Company has an important suburban district to provide for. The number of passengers carried has risen in 10 years from 7 millions to 12 millions per annum, and yet its station is one of the smallest and most ill-designed in Paris. By reference to plans the Author describes the improvements about to be effected, which, while they will not greatly alter the departure platforms and the booking offices, will entirely re-model the arrival side of the station. It is proposed to carry out these works in two sections, with an interval of a year between them. Those alterations which are considered most urgent will be put in hand so as to be completed in time for the Exhibition in 1900, and then, after a twelvemonths' delay, the works will be resumed, and the entire alteration will be carried through. The Author states briefly the conditions which engineers now consider to be indispensable in designing an important station, and he explains how it is proposed to comply with them in the present case. A series of plans indicate: (1) the existing station, (2) the changes to be carried out for the year 1900, and (3) the design to be ultimately realised. An illustration is given to explain the works in progress, and an elevation shows the station as it will be when all is finished. The cost of the buildings to be demolished will alone involve an outlay of over half a million.

G. R. R.

The Prolongation of the Orleans Railway to the Quai d'Orsay.

L. BACLÉ.

(La Nature, 1 October, 1898, p. 278.)

It is pointed out that the constant increase in the traffic and the needs of further accommodation have in turn compelled each of the chief railway companies having termini in Paris to re-

model and extend their stations. Among others the Orleans Company has been for some time considering this question. For certain portions of the traffic the removal of the station for Sceaux [1] from the Place Denfert to the Luxembourg, which took place in 1895, has effected all that was needed, and the results of this alteration, which entailed the construction of 1,640 yards of line, have proved in every way successful, and have led to an increase in the first year of 40 per cent. in the traffic. It has subsequently been decided to transfer the whole of the main station to the site on the banks of the Seine, occupied till recently by the ruins of the Cour des Comptes. The Orsay barracks, which are also being removed, rendered additional land in the vicinity available, and the negotiations with the Government for the purchase of the property were satisfactorily completed in 1897. The projected railway will consist of the prolongation of the two central lines of the existing station, which will start with a sharp decline towards the River Seine 481 yards in length under the Place Valhubert, and proceed from thence to the banks of the river, which will be reached at the Quai St. Bernard. The railway then passes alongside the river under the quays for a length of 710 yards to the Sully Bridge. Side openings facing on to the river will be pierced for light and ventilation. The level of the rails is approximately that of the ordinary water-level of the Seine. All the works will be executed as far as possible by means of tunnelling, in order not to interfere with the surface traffic. Plans are given of the station and elevations of the principal fronts towards the river and towards the Rue de Bellechasse, which latter frontage will be occupied by a terminus hotel. The booking-offices will be arranged on the level of the street, the platforms, 16·4 feet below, being reached by staircases and lifts. The station proper will cover a rectangular site of about 218 yards by 82 yards, and will contain fifteen lines of rails. As this station occupies one of the finest sites in Paris, in close proximity to the Tuileries Palace and to the Palace of the Légion d'honneur, it has been necessary to study the architectural details with great care, and this portion of the work has been entrusted to Mr. Laloux. A detail section is appended, in order to explain the construction of the principal tunnel and of the tunnel openings along the banks of the Seine.

G. R. R.

[1] Minutes of Proceedings Inst. C.E., vol. cxxiv. p. 473.

The German East African Central Railway. Von Schwabe.

(Annalen für Gewerbe und Bauwesen, 1 October, 1898, p. 125.)

The Committee for the above railway reported on 19th June, 1896, that—either by State aid or at the cost of the State—it was of the utmost importance that a railway should as soon as possible be constructed from Dar-es-Salâm to Ukami, with a junction to Bagamayo, as the first section of a line joining the German littoral in East Africa with the lake districts of Victoria-Nyanza and Tanganyika. The estimated expenditure for the first section of the above line was £592,500, and it was probably chiefly on the score of the cost that the project has hitherto remained abortive. Reference is made to the proposals for other German colonial railways, and to the scheme for the English line from Mombasa to Lake Victoria-Nyanza, likewise to the colossal project of a railway to be undertaken from Buluwayo to Lake Tanganyika by the Chartered Company. Attention has recently again been directed to German colonial enterprises by the speeches of Mr. von Bennigsen, and the Author proposes to give further details concerning the Central African railways. Sketch profiles are given of the English Uganda Railway, the projected Northern-German line and the Middle-German line to the same scale, the total lengths being respectively 656 miles, 497 miles and 909 miles. A proposed southern line, advocated by Governor Freiherr von Scheele, is here, for reasons given, omitted. Various estimates of the cost per mile of these different lines have been put forward, but it is shown that at the actual minimum outlay on the Uganda Railway of £2,700 per mile, the Central German line, which, with its branches, has a total length of 1,086 miles, would need an expenditure of upwards of £2,940,000. Some account is given of the colonial imports and exports and of the growth of revenue from 1891 onwards, and various considerations follow respecting the best methods of developing the resources of the country by the use of waterways to the utmost extent, and by the improvement of the roads and caravan routes to the interior. Allusion is also made to the Author's plan for a narrow-gauge railway using the common roads.

G. R. R.

Swiss Railways of the Rack-Rail System.

E. Strub, Civil Engineer, Interlaken.

(Organ für die Fortschritte des Eisenbahnwesens, 1898, p. 140.)

The first three of the eleven railways referred to in this Paper are of the standard 4 feet 8½ inches gauge, with long radius curves and two-axled vehicles. These lines did not pay, and this checked for a time the further extension of the system until, in 1898, the

Pilatus Railway gave a fair return for the capital invested; the width of gauge having been reduced, and radii of curves increased about half, thus allowing the employment of locomotives with three, and carriages on four, axles. These reductions proved too great, and the gauge in later times was increased to 3 feet $3\frac{3}{8}$ inches, and the minimum radius to 80 and 90 metres. Electricity supplanted steam-power, and the locomotives and cars were combined without greatly increasing the cost, while the carrying capacity was doubled and the safety increased. The Gornergrat[1] and Jungfrau lines are now capable of carrying twice as many passengers with the same dead weight as the first five railways. Experience has shown that the increased radius should not be less than 550 yards, nor the gradients more than 1 in 4, and gauge not less than 3 feet $3\frac{3}{8}$ inches. The permanent way since the reconstruction of the original lines is fundamentally the same in all—3·93 inches height of rail, weight 40·32 lbs. per yard, with cast-iron sleepers bedded in concrete. There are four distinct varieties of rack-rails, the latest, that on the Jungfrau line, is on the Strub system (described at page 151 of the Organ for 1897), and combines the safety of the "Pilatus," the durability of the "Luter," and the lightness of the "Platten" systems, without any of their defects. The locomotives are of five varieties. The carriages are built mostly on one system. A Table in the Appendix gives at a glance the principal details of eleven Swiss railways worked on the rack-rail system.

W. A. B.

The Electric Rack-Railway on the Gornergrat.

(Schweizerische Bauzeitung, 1898, p. 116 *et seq.*)

This is a long and detailed descriptive article running through Nos. 16 to 21 inclusive of the journal. It is pointed out that until comparatively recently Zermatt, Visp, and Wallis were difficult of access. Whereas in 1838 there were only about twelve tourists in Zermatt, there were in 1894 about 20,507. From Zermatt many tours are made, and the Gornergrat, 10,200 feet high, is one of the chief resorts. It was considered desirable therefore to connect this point with Zermatt by rail, and a sketch of the history of the undertaking is given. The firm of Haag & Greulich undertook the work, and prepared plans in 1894. It was thought possible to employ the power of waterfalls and to work the line by electricity, and though the initial cost would be higher than if steam-power were used, the cost of maintenance would be much less. The line is about 5·6 miles long, and the cost was estimated at £130,000, and maintenance at £3,360 per

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[1] See next Abstract.

annum. On the 11th January, 1896, the tender of Messrs. Haag & Greulich was accepted to construct the line for the sum of £120,000, including rolling-stock and electrical equipment. The terminus at Zermatt is 5,300 feet, and the Gornergrat Station 9,900 feet, above sea-level, which is the highest point yet reached by any railway.[1] The total rise is therefore 4,600 feet in 5·63 miles, and the steepest gradient is 1 in 5. The journey occupies 90 minutes, and 110 passengers are carried at once. Tunnelling was carried on all through the winter of 1896–7 by 150 men, and as many as 1,100 men have been employed at once.

Mountain sickness became common at the summit. The various forms of road-bed are described and illustrated, and details are given of the construction of several bridges and tunnels. The gauge of the line is 1 metre, and the sleepers are of steel, with the Abt double rack. For the power installations tenders were invited from the chief European electrical firms. The result was that Brown, Boveri & Co. supplied the electric plant, T. Bell & Co., of Kriens, the turbines, the Swiss Locomotive Works, Winterthur, the locomotives, and a Neuhausen firm the carriages. The water-power plant at Findelenbach consists of three high-pressure Girard turbines running at 400 revolutions, and each capable of developing 250 HP. One of these is a reserve plant. The electric plant is on the three-phase system, and the generators are coupled direct to the turbines. The exciter is also driven by a turbine. The potential is 5,400 volts at forty periods per second, and feeders are carried to various points on the line where the potential is transformed down to 540 volts for use. Each locomotive weighs 10·5 tons, and has two motors of 90 HP.

E. R. D.

Power Consumption on Electric Railroads. S. T. DODD.

(Journal of the Association of Engineering Societies, August, 1898, p. 68.)

In considering the power necessary to propel an electric street-car, the Author first investigates the frictional resistance, and arrives at the following formula, which fits the result of about twenty of the most trustworthy observations he could get, for the resistance in lbs.:—

$$(20 \cdot 16 + 0 \cdot 22\ V)\ E + (7 \cdot 84 + 0 \cdot 22\ V)\ T,$$

where V is the velocity in miles per hour.
E the weight of engine or motor car in tons.
T the weight of trailing cars in tons.

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[1] The summit tunnel of the Lima and Oroya Railway in Peru is 15,600 feet above sea-level. Minutes of Proceedings Inst. C.E., vol. lv. p. 388.—SEC. INST. C.E.

He next shows that the force in lbs. per ton required to accelerate the car equals

$$102 \cdot 3 \times F,$$

when F is the acceleration in miles per hour per second. This he compares with the force required to mount different gradients; and the Paper concludes with a number of numerical examples.

A. W. B.

Improvement in Railway Couplings.

H. WICK, Chief Foreman Bavarian State Railways.

(Organ für die Fortschritte des Eisenbahnwesens, 1898, p. 97.)

The Author assumes the strain developed, under ordinary circumstances, by a goods locomotive to be equal to about 5·9 to 6·9 tons, and very much greater under certain exceptional conditions. The safety of the traffic and the comfort of the travelling public call for the more general employment of continuous draw-bars that will relieve the wagon-frames of all unnecessary strains and afford greater elasticity. The arrangement illustrated in this Paper, it is claimed, fulfil these requirements. The two draw-bars are coupled and keyed together; each is provided with a spiral spring capable of a resistance of 7·87 tons; these springs are fixed back to back and are allowed 6 inches play. One of the springs is inserted under compression equal to 330 lbs.; the other under compression equal to 3,300 lbs. With this arrangement, as the strain comes upon the draw-bar, the first spiral spring is compressed until the strain exceeds 3 tons, when both springs come into play, and act as long as the strain does not exceed the combined resistance of both springs.

W. A. B.

Electrical Locking-Bar.

(Organ für die Fortschritte des Eisenbahnwesens, 1898, p. 157.)

With a view to the more effectual protection of trains standing in or passing through a railway station, Messrs. Lorenz, of Berlin, have brought out an electrical arrangement by which a signal is shown for every line occupied. Parallel to, and on one side of the rails,] shaped rails on spring chairs are fixed; these rails are rather longer than the extreme wheel-base of any wagon or carriage. An iron box, containing the mechanism (which is fully described), is bolted to the] piece, and moves on a pivot whenever the outer flange of any wheel comes upon it. This movement breaks electrical contact, interrupts the current, and works the

tell-tale. All the locking-bars on one line of rails are connected up in one circuit, so that as long as any vehicle is on that particular line its signal stands at danger. These] rails are so balanced that pressure on any part of them is sufficient to work the signal. The spring chairs, however, offer such resistance that nothing less than the weight of a wagon depresses them; at the same time they are so elastic that an express train passing over them in no way injures the mechanism.

W. A. B.

Automatic Electrical Block System.

(Organ für die Fortschritte des Eisenbahnwesens, 1898, p. 161.)

The electrical locking-bar, described in the preceding abstract, has been further adapted and extended so as to record by visible and audible signals the entrance into and occupation, by a train, or single engine, or wagon, of any particular track of rails, at the same time preventing the signals being lowered, and the points moved, as long as there is any vehicle standing on the line. Further, it automatically locks the lever-handle of any switch or signal, and frees it only when the rails are clear.

The locking-bar is connected electrically with the apparatus in the signal-box or station building. The current is always on; the connecting wire passes round an electro-magnet, the armature of which engages a stop on a disk actuated by a weight. When an engine or wagon depresses the locking-bar the circuit is interrupted, the armature freed, the catch disengaged, and the disk revolves through 90° and is then arrested by another stop. This movement causes a danger signal to appear, and starts a sounder; at the same time the outside signals and points are worked and locked. When a train or wagon clears the track, the locking-bar rises and again closes the circuit, the signals and points are released, and things return to their normal position. This process is invariable and the failure of any part is at once indicated. If the current is too weak, or the connections at fault, the armature is released and the line is blocked. The force exerted by the electro-magnet is equal to 60 grains. One winding up of the weight is sufficient for 320 trains; before it descends to its lowest position a sounder rings, and the points and signals are set at danger, so that every possibility of accident is provided against. The whole mechanism is minutely explained in the letterpress and by four diagrams.

W. A. B.

Rail-Brakes and Skids on Shunting Inclines.[1] VON SIGLE.

(Organ für die Fortschritte des Eisenbahnwesens, 1898, p. 185)

The Author remarks that the universal adoption of this simple mode of shunting has been retarded by the damage occurring to both rolling-stock and goods; he then proceeds to show that, by an improved construction of skid, and arrangement of brake rail, as explained in his Paper, these objections have been removed.

The idea is to stop the wagons that have been run down an incline by means of a skid laid on the rails. This skid is made with an external flange projecting beyond the rail and bent down at right angles; this presses against a guide rail bolted on the outside of the rail. As soon as the skid comes to the end of the guide it is thrown off. In practice, however, this did not invariably occur; so, to insure the skid being thrown off at the desired point, a wedge was bolted to the line rail, and this coming in contact with the bent flange forces the skid off the rail.

This improved construction has been in operation for the last 2 years at Speldorf, and a number of other large shunting stations, with perfectly satisfactory results.

By slightly lubricating the skid its life has been prolonged, and the jolt on mounting very much reduced. The ramps have been raised to 6 feet and 8 feet in height, with an incline of 1 in 50, which is sufficient to carry the wagons to the extreme point they are required to run. The length of the guide-rails varies from 40 feet to 100 feet in length, according to circumstances. A very great reduction in the working expenses has been effected under the improved system of Mr. Bussing, of Brunswick, whose skid the Author has found by experience to be most satisfactory.

Diagrams fully explain the construction and working of this arrangement.

W. A. B.

The Electric-Lighting of Railway Post Wagons. POHL.

(Archiv für Post und Telegraphie, 1898, p. 1. Plate and Figs.)

The article gives full details of the experience gained from 4 years' use of electric lighting. It appears that secondary batteries are used, and the light has proved far superior to that formerly obtained from oil-gas. The general lighting is not so good, but the lamps are now placed where most useful, and hand-lamps are also available. There is a distinct saving in dead weight of 1,200 lbs. on cars 39·5 feet long, and of 710 lbs. on cars 32·8 feet long.

The initial cost of electric lighting a car 32·8 feet long for

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[1] "Organ," 1896, p. 19.

letter and parcel traffic is £19 17*s.*, a similar car for letters only £26 8*s.*, and one 39·5 feet long £29 19*s.*, while the initial cost for oil-gas lighting was £49 10*s.*, £60 13*s.* and £75 11*s.* respectively. Sirius glow-lamps are used, costing 8·4*d.* each. The average life is found by tests to be 211 hours, the average light given is 1,809 candle-power, and the energy used 4,868 watt-hours; a lamp is not used for more than 200 hours. The batteries are of the Boese type, each consisting of four sets of four cells of nine plates each, and weighs 404 lbs., gives 32 volts and 120 ampere-hours. Some improvements in the plates have recently been made. A detailed wiring-plan and diagram of connections is given.

The maintenance costs are given in very great detail, and it appears that for 12 months the outlay was £8,200, and it was not possible to compare this directly with the cost of oil-gas lighting. The glow-lamps used were 12-candle power, and the gross cost per lamp-hour was 0·42*d.*; the comparative cost for oil-gas would have been 0·54*d.* The Author calculates that by the substitution of electricity for oil-gas in 1,108 cars now altered a yearly saving in maintenance of about £3,350 has been effected, and if the diminished initial outlay be considered, then a total yearly saving of £5,350 has been effected.

E. R. D.

Compound Three-Cylinder Locomotive for the Jura-Simplon Railway. R. Weyermann.

(Schweizerische Bauzeitung, 1898, p. 46.)

Since the formation of the Jura-Simplon Railway Company in 1890, by the fusion of several lines, some of narrow gauges, the annual total of loads drawn by the ordinary gauge type has risen 40 per cent.; speeds and weights of rolling stock have also increased. It became necessary to use two locomotives, so thirty two-cylinder compound engines were obtained between 1891–6. These are used on the main line express service, and their greatest speed is 56 miles per hour. For the heavy gradients also a specially powerful type of engine was needed with lower speed. There are at present 225 normal-gauge engines of seventeen different types, whereas six or seven types would be quite sufficient for the 625 miles of line. The Author then gives a list of requirements for the new type of locomotive for specially heavy traffic, and states that an order was given for an engine to the Winterthur locomotive works, and it has now been in use some time. It is a three-cylinder compound engine, with the high-pressure cylinder between the frames and two low-pressure cylinders outside. The chief dimensions are: high-pressure cylinder, 19·6 inches in diameter; low-pressure cylinders, 21·25 inches in diameter; stroke, 23·5 inches. The low-pressure

cylinders actuate one axle and the high-pressure cylinder another, the three cranks being at 120° apart, and there are six wheels coupled on a pair of leading wheels. The steam-pressure is 206 lbs., weight of the engine empty 48·5 tons, loaded 53·6 tons; maximum speed 46·4 miles per hour. Total weight of locomotive and tender loaded 82 tons, length over buffers 52·5 feet. In 1897 the consumption of coal averaged 43 lbs. per mile. The trials have proved so satisfactory that twenty-five similar engines have been ordered for delivery in 1899.

E. R. D.

The Fraser Electric Elevator. A. E. B. Ridley.

(Journal of the Association of Engineering Societies, September, 1898, p. 92.)

In the elevator two large pulleys are fixed alongside one another at the same height; over one pulley pass steel ropes carrying the cage and the counterbalance weight. A steel rope from the counterbalance weight passes over the other pulley and is connected to a frame; both the counterbalance and the frame carry a sheaf of hanging pulleys underneath. Continuous Manilla ropes pass over each of these sets of pulleys, the upper and lower bight of the ropes being driven by grooved pulleys worked by two electric motors. If the electric motors revolve at the same rate, the counterbalance, &c., remain at rest; but if one revolves quicker than the other the counterbalance weight either ascends or descends, causing the cage to descend or ascend accordingly—the rate of its motion depending on the difference in the speed of the motors. The latter are shunt-wound and connected in parallel. The field coils of each are wound in sections, the ends of which are connected with a number of buttons in the car. The attendant, by moving a lever in the car, cuts out the different sections at will, and so increases the speed of the armature of either motor according to the direction in which he moves the lever. The automatic starter is so arranged that when a latch is lifted by the operator the motors are started, and when he drops the latch, which can only be done when the lever is in the centre, the current is cut off. A powerful brake, applied by means of a spring, grips the sides of the main overhead sheaf, except when the current is on, which releases the brake. With this arrangement the motors are never started or stopped with the load on.

A. W. B.

Air-Buffer for Passenger-Lifts.

(American Engineer, New York, 1898, p. 308.)

Each elevator shaft of the new "Empire Building," in New York, is walled up independently as high as the third floor, and is made a close fit for the car, the last 50 feet of the drop of each elevator thus forming an air-cushion. The elevator cars may fall on to their cushions, whereupon the air is confined in the bottom of the shaft, and, by its gradual escape, lets the elevator down easily without shock. It is stated that a car has been dropped from the twentieth floor of this building without breaking eggs, and electric glow-lamps that were placed on the floor of the car. The pressure of the air caused by a fall from the top floor, a height of 290 feet, is calculated to be about 3½ lbs. The estimated proportion between the depth of the air-cushion and the length of the drop is as 1 to 6. The advantages of this safety device are:—simplicity, reliability, absence of moving parts and the sacrifice of no room that could be used for any other purpose. The only precaution necessary seems to be to make the doors of the lower-floor entrances air-tight.

Experiments on the Accuracy of Arndt's "Econometer" for Measuring the CO_2 in Boiler-Gases.

(Bulletin de la Société Industrielle de Mulhouse, April-May, 1898, p. 71.)

This German instrument has for its object to show the amount of CO_2 in the flue gases from boiler-furnaces, and thus to afford an indication of the state of combustion at the time of testing. The apparatus consists of balance scales enclosed in an air-tight glass vessel. At one end of the scale is a glass sphere filled with the gases of combustion, and cooled to the temperature of the external air; the other end carries a needle moving along a graduated scale. The outer glass vessel is filled with atmospheric air, and the CO_2 inside the sphere being heavier than the air sinks, the amount of its depression being indicated by the pointer. The scale is so marked off that No. 1 division corresponds to a difference of 1 per cent. in the proportion of CO_2 in the flue gases.

Elaborate experiments were made to check the results obtained with the econometer by analyzing simultaneously the gases, from the same place in the flues, with an Orsat apparatus. From this analysis of the CO_2 an endeavour was also made to determine exactly how far the dampers should be opened, to give the best combustion in the particular boiler tested. Two sets of trials were carried out, first with 11½ lbs. and secondly with 14·7 lbs. of coal burnt per square foot of grate per hour. Eight elephant smoke-tube boilers with economiser were tested, each having 1,400 square feet of heating surface. The coal used was French and Belgian, with a heating value of about 13,700 B.T.U.

per lb. The econometer communicated with the chimney flue on the boiler side of the damper, and care was taken that similar gases reached it and the Orsat apparatus. The gases were sampled over water covered with a film of oil, but the percentage of CO was not determined.

A first set of experiments were made, when burning 11½ lbs. of coal per square foot of grate per hour, to determine the percentage by volume of CO_2 from the eight boilers. In one case the results from the Orsat apparatus and the econometer agreed; in six cases those with the Orsat were higher by 3·36 per cent., and in one case the econometer gave the higher results. The mean difference between the two was only 1 per cent., the Orsat apparatus giving the higher when the percentage of CO_2 was greatest, and the econometer when it was less. These observations were the results of several readings of the econometer and three analyses, and it may be assumed that, under those conditions, the indications of the econometer are sufficiently accurate for practical work.

In the second set of experiments made on the same boilers, when burning from 13 to 14 lbs. of coal per square foot of grate per hour, the Orsat gave 6·39 per cent. lower readings than the econometer. The main percentage of CO_2 with both instruments was less than when the boilers were moderately worked, being 16 per cent. lower for the Orsat and 7·2 per cent. for the econometer. The variation between the two sets of observations was double that in the first series of tests, and the econometer cannot, therefore, be relied on to give readings as accurate when the boilers are worked at 13 lbs. to 14 lbs. per square foot of grate per hour, as at 11½ lbs.

It is a disadvantage of the econometer that its readings cannot be depended on when the boilers are forced, as it is under those conditions that it is of great importance to know the most economical rate of combustion. Thus its indications are not so accurate with boilers worked at very different rates of evaporation; but for boilers worked steadily and at a moderate rate of combustion it may be employed with great advantage, and, as it quickly indicates any variation in the percentage of CO_2, defects of the grate or in stoking can be at once remedied. Unfortunately it ought always to be carefully adjusted to the prevailing barometric pressure—an operation which cannot be left to the stoker.

The extent to which the dampers should be opened was also studied, but the best guide is to know the percentage of CO_2, CO, and oxygen, in the flue gases. No boiler experiments are complete without this percentage, and unless it is determined the results obtained are often misleading. When the econometer is used, its indications should be carefully checked from time to time by analyzing the gases. It gives only the percentage of CO_2, not that of the CO or the oxygen. It is important, however, to know the latter, as from it the percentage of air in excess, beyond what is required for the combustion of the fuel, can be calculated. B. D.

On the Importance of Cleaning Steam-Boilers when Cold.

(Bulletin de la Société Industrielle de Mulhouse, April-May, 1898, p. 66.)

It is a bad system to empty boilers under steam pressure, when they have to be cleaned, to remove the deposit adhering to the boiler plates. This is the usual method with stokers, but there are two great inconveniences connected with it. The internal surfaces of the boiler plates are exposed to radiation from the hot surrounding brickwork, and the deposit during the process of emptying adheres to them and cannot be removed except by hammering. In the second place the riveted joints, affected by the radiation, and no longer covered with water, soon have a tendency to leak. Boilers should never be emptied until the steam pressure has fallen to about 1 atmosphere, or even less, and should be allowed if possible to become quite cold. The process of cleaning them thus, by means of a hose and water-jets, after carefully drawing off the water, is due to Mr. Savreuse of Amiens. Since 1886 it has been used for many boilers in France, and they have always been found very clean inside afterwards, the deposit comes away easily, and there is no necessity for chipping. To cool a boiler completely, when surrounded by brickwork, takes about 8 days altogether. After 3 days the flues can be cleared of the cinders and soot, and this helps to cool the water. A small steel scraper will be found useful to remove the harder deposit.

B. D.

Accidents to Steam-Boilers.

(Annales des Ponts et Chaussées, 1898, p. 265.)

A tabulated *résumé*, taken from the official reports, of the whole of the accidents occurring to steam boilers in France during the year 1896. The information given comprises the date and situation of the accident, details of each boiler, the circumstances attending the accident, and the consequences and presumed cause of each accident.

In eighteen cases defective design and workmanship was the cause of the accident, the principal defects being: (1) parts made inaccessible to complete inspection; (2) tubes of too large diameter and too thin; (3) copper fire-box above the level of the water, and unprovided with safety appliances; (4) copper of too thin a gauge; (5) fire-door opening too weak; (6) supply-pipes not provided with expansion joints; (7) stay-bolts badly made; (8) cast-iron parts of bad design, or subject to unequal expansion; (9) plates of too low a grade for the strains to which they were submitted.

Defective maintenance was the cause of fourteen accidents

through: (1) corrosion of plates and other parts; (2) wear and deterioration of brass smoke-tubes; (3) wear and defective repair of a copper fire-box; (4) overstraining of a stay-bolt; (5) defective making of joints.

Careless working caused fifteen accidents, viz., in five cases through shortness of water, and in seven cases through want of cleaning, in one case through an excess of pressure, and in two cases through tightening joints while under steam. In five cases the causes of the explosion were not ascertained.

Further Tables classify the accidents according to: (1) the class of work for which the boiler was employed; (2) the type of boiler; (3) the presumed cause of the accident. The total number of accidents dealt with was forty-four, which resulted in injuries to twenty-five men and death to sixteen.

Three Plates with fifty-four figures, showing details of failures, illustrate the Paper.

H. I. J.

The Application of Graphical Interpolation in Machine Design.

A. S. OSTREICHER.

(The Engineer, 28 October, 1898, p. 412.)

In making graphical tables for machine elements it has been found expedient to sketch, roughly, the two extreme sizes and check the principal dimensions by calculation, correcting the designs accordingly. The principal dimensions of a size midway between the extremes can be readily checked by calculations; if these are not the mean of those of the extremes, the range between the limits is too large and is reduced till this is so. Then, all other intermediates can be found as follows: Draw out the design of the largest size, and draw a series of equidistant parallel lines to the axes of the drawing—as many as the number of consecutive sizes required. Project the important points on to the first of the parallels, and on the last lay down the corresponding dimensions of the smallest size. Join the similar points by straight lines, then the intersections of the latter with the other parallels give the dimensions of intermediate sizes.

A. W. B.

Tests of a Triple-Expansion Steam-Pump at the St. Gall Waterworks. A. STODOLA.

(Schweizerische Bauzeitung, 1898, p. 54. 3 Figs.)

The new pumping-station of St. Gall was set to work in the spring of 1895. The town being insufficiently supplied with water, a new source in the Bodensee was chosen, at a distance of

6·2 miles and a difference of level of 984 feet. In order to avoid impurities, the suction-pipe is carried out 436 yards from the shore into a depth of 130 feet to 150 feet of water. The whole plant was built by Sulzer Brothers, of Winterthur. The water is pumped through a pipe 446 yards long and 20 inches diameter, and delivered to the filters, whence it passes by gravity to the reservoirs. There is also a pump used for compressing air. These pumps are driven by a triple-expansion steam-engine, and space is left for an electrically-driven plant, which will be supplied with current from the waterfall at Goldach; this current will only be used for pumping from 10 p.m. to 6 a.m., while during the day it will be employed for the electric tramways of St. Gall. The tests referred to took place from the 25th to 30th March, 1898. The boilers were fired with coke from the municipal gas-works, and as the coke was largely in the form of dust, separate tests were made with the sifted and unsifted fuel. Details are given as to the methods of observation employed. An analysis of the coke showed combustible matter to be from 71·7 per cent. to 89·6 per cent., and ash 7·2 per cent. to 17·5 per cent. Analysis of the flue gases in three cases showed no CO, in one case traces, and in one 4·1 per cent. The general results are given in the form of a very complete table, from which the following details are taken: High-pressure cylinder, 14·1 inches diameter; intermediate cylinder, 23·75 inches diameter; low-pressure cylinder, 34·5 inches diameter; stroke, 39·37 inches; speed, 60 revolutions per minute. Boilers of the Sulzer tubular type, and Green's economiser, and a tubular superheater are used. The temperature of water from the economiser was 132° F.; flue gases before reaching economiser, 387° F.; after leaving it, 180° F.; steam-pressure, 150 lbs. per square inch; power developed, 210·5 I.HP.; work in water pumped, 169·88 HP.; steam consumed, 12·1 lbs. per I.HP. hour; coke consumed per pump-HP. hour, 1·6 lbs.; commercial efficiency, or the relation of pump-HP. to indicated HP., 81 per cent.

E. R. D.

Recent Progress in the Development of Pneumatic Dispatch Tubes. B. C. BATCHELLER.

(Journal of the Franklin Institute, vol. cxlvi., 1898, p. 81.)

After a short historical account of the introduction of pneumatic dispatch-tubes, the Author proceeds to describe the 6-inch and 8-inch tubes now in use in America for the carriage of mail. In these large sizes the weight of a carrier and its contents is considerable, and necessitates arrangements to stop it gradually. Small tubes, up to 3 inches in diameter, in use in London and elsewhere, are operated both by currents of compressed or by currents of rarefied air, but the American 6-inch and 8-inch lines

are all worked by compressed air. If compressed air is used, and the pipes are laid underground, water will be kept out and not drawn in through any leaks. Air-cushions for checking the speed of the carriers at the stations are more efficient, and the gear operating the sending and receiving apparatus may be made smaller when compressed air is used. Owing to the reduction in temperature of the air, as it expands in the tubes, moisture is deposited, and in order to avoid this, as far as possible, the same air is used over and over again.

The sending and receiving apparatus are to a large extent automatic, and in connection with the former a dash-pot is used to prevent the too rapid dispatch of carriers; the period varies from 6 seconds to 15 seconds, depending on the length of the line. Intermediate stations are arranged to automatically discharge carriers intended for them, but to allow all others to pass on. This is effected electrically, with the aid of different-sized disks, in the end of the carriers.

The straight tubes are of cast-iron, accurately bored, and the bends of brass bent to a radius of twelve times their diameter.

The speed of the carriers is very great, a line 3,000 feet long being traversed in less than a minute.

The article is illustrated, and details of the location of a stoppage by measuring the time between the sound of an explosion and the echo are given.

W. B.

Temperature in Deep Mines. J. Sterling.

(Transactions of the Australasian Institute of Mining Engineers, 1898, p. 94.)

The following results, showing the rate of increase of rock temperature, were obtained at Lansell's 180 Mine, Bendigo, Australia :—

Depth. Feet.	Increase of 1° F. for every
454	110 feet.
1,294	182 „
1,750	173 „
2,295	152 „
2,701	137 „
3,110	110 „
3,250	111 „

The mean result of these ratios shows that the ratio of 1° F. for every 137 feet in depth is the record of the Silurian rocks of Bendigo.

B. H. B.

Results obtained in Driving the Sea Adit of the Bouches du Rhône Coalfield.

(Comptes Rendus mensuels de la Société de l'Industrie Minérale, 1898, p. 179.)

In the long drainage gallery which has been undertaken to connect the mines of Trets and Fuveau with the sea, near Marseilles, driving by means of electric boring machinery has been very successfully adopted. The rock traversed is Urgonian (lower cretaceous) limestone, sufficiently uniform and compact in character to admit of the use of rotatory boring machines, without requiring timbering or walling. The Bornet electric boring machine is used, taking the current from a dynamo driven by a turbine, the power being derived from a feeder of water encountered in the workings giving a pressure of 120 lbs. The same dynamo works a Mortier ventilating fan and the lamps for lighting the workings. The material broken in the face, which in June 1898 was 5½ kilometres from the level mouth, is carried out by an endless rope haulage. The work is done in three shifts of 8 hours, seventy-six shifts, or 26 days having been worked in the month in question. The results obtained were—

	Metres.	Feet.
Average length driven in 24 hours .	5·676	18·60
,, ,, ,, per shift .	1·892	6·20
Maximum length driven in 24 hours	6·700	22·00
Average advance per volley fired .	0·964	3·16

Two volleys or rounds of shots are fired as a rule in each shift (178 in 78 shifts). The average time for each volley is 4 hours 4 minutes 42 seconds, divided as follows :—

	H.	M.	S.
Adjusting the machine in position . .	0	24	0
Actual boring time	1	57	5
Loading and firing	0	19	24
Time lost for smoke to clear	0	21	4
Removal of broken stuff	1	0	36
Time actually lost	0	2	33

The 153 volleys, in June 1898, required the boring of 1,791 holes, of a total length of 1828·7 metres. The average number per volley was 11·7 of 1·021 metre depth. Five hundred and thirty-two borers were blunted, or an average of three and a half per volley. The work is done by each shift independently; the distance driven is measured up, settled between the men at each change (any points in dispute being settled by the respective foremen), and premiums are awarded daily to the men who have realized the maximum quantity of work.

H. B.

The Value of Various Descriptions of Wood for Pit Timber.

C. DÜTTING.

(Glückauf, 8th October, 1898, p. 797.)

Comprehensive experiments have been for some time past in progress in the Government Collieries at Saarbrücken, to test the utility of various kinds of timber for employment in mines. One reason for undertaking these tests was the steady diminution in the use of beechwood for these purposes, notwithstanding the fact that the mines in question are situated in the midst of splendid beech forests. The principal objects in view were to ascertain the respective value of beechwood props and of acacia wood props, and to determine whether any of the known processes of timber preservation could be employed with advantage in the case of these woods. It is observed that there has recently been a great reduction in the price of fir timber, which may to some extent have prejudiced the employment of beechwood. The price of fir is, however, now rising, and inquiries are being made for cheaper descriptions of wood. In these collieries a sum approaching three millions of money has been expended upon timber alone during the 21 years ending 1895, and thus any saving in the matter of the outlay upon wood is important. The descriptions of timber used in the experiments were as follows: beech, oak, fir, and pine. In lieu of conducting the tests in the usual way with small cubes of sound wood, it was decided to use the props entire, as sent to the pits in lengths of from 3 feet to 8 feet. Five sets of tests were made with each description of timber and the results are given in Tables. The beech samples in each case were superior to the other descriptions of timber. The props were exposed to weather above ground and in the pit, and were tested in various ways, and the Author states that the objections which have been urged against beechwood were not sustained, whereas the excellence of oak timbering for use in the pit has apparently been overrated. Corresponding experiments were made with the wood of the acacia (*Robinia pseudo-acacia*), which is said to flourish well on poor soil and to send up shoots from the rootstock, which in about 15 to 20 years attain proper proportions for pit-props. It has been asserted that this timber surpasses oak in strength and durability. The acacia gave favourable results under these tests, but its weight and its relative costliness would militate against its employment. Its growth on suitable soil would seem to be extremely rapid. In conclusion, reference is made to certain preservative solutions, which have been proposed for increasing the durability of pit timber, but these trials are not yet complete.

G. R. R.

Coals of the Basin of the Donetz. Captain KHUDINTZOV.

(Morskoi Sbornik, November, 1898, non-official past p. 137.)

Cardiff coals for the Black Sea fleet were superseded 10 years ago by coals from the Donetz basin, and in 1897 the first contract was made for the supply of these coals to the Baltic fleet. This coalfield extends over a large portion of New Russia, from the Don to the Dnieper. Ordinary coals are found in the western part and anthracite in the eastern part of the district; the change from one to the other taking place gradually, so that a great variety of coals is found. The Author gives a short account of the development of the coal industry. Peter the Great is said to have initiated it in the early part of the last century. Systematic search for coals was commenced in 1735, and in 1740 the result of the first geological survey, under the direction of a Frenchman, Le Plé, was published. Working coals now commenced and increased rapidly. In 1798 the first iron foundry was started at Lugansk. Deficient transport prevented the development of the mining industry till, in 1864, the railway was opened from the Grushevka anthracite mines to Rostov; and in 1870, the Kursk-Kharkov-Asov railway, to serve the western part of the coalfield. Since then the output has continued with increasing rapidity. A diagram is given showing this rapid increase, from 60,000 wagons in 1880 to 430,000 in 1897, each wagon containing 600 poods (9·67 tons). In 1830 shafts were sunk for the first time, previous to that workings had all been from the surface only. The Author tabulates the ordinary coals in five groups, according to quality and composition; the lowest quality having a specific gravity of 1·25 and 75 to 80 per cent. of carbon, and the highest a specific gravity of 1·35 to 1·4 and 90 to 93 per cent. of carbon. Besides these there is the anthracite with a specific gravity of 1·4 to 1·8 and 93 to 95 per cent. of carbon. The Author deals very fully with the question of analysing coals, and insists on the necessity of systematic analyses being made at the pit in order to sort the coals into qualities suitable for different industrial purposes. He explains at length the methods adopted by the Government analysts for securing correct samples of coals, and for conducting the analyses. He then gives Table I of the results of analyses of coals for moisture, volatile products, ashes and sulphur, of forty-six samples of coals, by Prof. Alexëev, in 1897. This is followed by Table II, giving fifteen complete analyses, conducted at the Sevastopol Chemical Laboratory, of coals delivered into that port during 3 months of 1897, and some deductions from these two Tables.

C. H. M.

Separation of Ores by Magnetism.

Dr. H. Wedding, Government Inspector of Mines.

(Verhandlungen des Vereins zur Beförderung des Gewerbfleisses, 1898, p. 263.)

In a Paper of twenty-four pages with two sheets of illustrations, the Author, after describing the force and action of magnetism, refers to the attention lately devoted to the above subject and how this process is gradually supplanting the older ones.

Magnetism, he points out, is applicable to the treatment of magnetic iron ores, such as apatite; calcined ores, viz., spathic iron and its compounds. Specular copper ore, sulphuret of zinc, calcium and galena, are by the same force separable from iron ores, and red and brown hematite, and native spathic iron from each other and from their compounds.

Permanent magnets are applicable in the first two instances, while electro-magnets may be used in all, and must be in the fourth case.

The magnets are in some instances protected by sheets of zinc or copper. Permanent magnets and electro-magnets are variously employed. The arrangements and processes at present in use are accurately described, and sufficiently illustrated to give a complete idea of the machines invented by Beuther, Busse and Seloe, W. von Siemens, Reed, Kessler, Edison, Max Putzig, and Siemens and Halske.

The Author further gives the results of numerous experiments actually made with iron, zinc and other ores, and concludes with the remark: "That though there are innumerable questions still to be solved, yet the results already obtained are certainly calculated to provide purer iron, and to lead also to the reopening of abandoned workings, and the wider extension of iron-producing industries throughout the world."

W. A. B.

The Use of Blast-Furnace Gases in Gas-Engines.

Aimé Witz.

(La Revue Technique, 10th October, 1898, p. 437.)

At the instance of Mr. Greiner, the general manager of the Société Cockerill at Liége, the Author has been engaged for some time past in studying the use of the furnace gases from the company's ironworks for gas-motor purposes. It was decided to submit the engine under trial to a 24 hours' continuous test, doing its normal work at a rate of 90 per cent. of possible explosions. The engine in question was of the "Simplex" type, and was

constructed at the Cockerill works. The cylinder was 31½ inches in diameter, stroke 39·3 inches. The engine made 105 revolutions per minute, and was of 200 HP. nominal. The gas was taken from the furnaces, without any special treatment, either direct or through a small gasometer, containing 10,700 cubic feet. The power developed was tested by means of a brake. A Crosby indicator was used to take the diagrams and to calculate the indicated work. The volume of gas used was determined by graduating the gasometer, and each of these volumetric trials lasted for 29 minutes, during which samples of the gas were withdrawn for the estimation of the calorimetric values. By means of barometric observations and temperature readings it was possible to reduce all the results to a mean atmospheric pressure of 30 inches and zero temperature respectively. The results are set forth in Tables, from which the following figures are extracted: mean consumption of gas hourly 21,362 cubic feet; mean effective HP. 181·16; use of gas per HP. hour 117·5 cubic feet. There was but little variation either in speed, effective HP., or in the calorific value of the gases during the experiment. The water employed was about 22 gallons per HP. hour, and the use of oil and grease was trifling. No troubles were caused in the cylinder by the dust from the furnaces and the gas-motor [1] worked throughout as steadily as a steam-engine.

G. R. R.

On the Slag of the Basic Open-Hearth Furnace. O. Thiel.

(Stahl und Eisen, 1898, p. 750.)

The slag produced in the treatment of phosphoric pig-iron by the basic method in the open-hearth furnace is, under ordinary conditions, of small value for agricultural purposes, containing less phosphoric acid and more silica and iron than that of the basic converter—the last constituent in particular being due to the long duration of the final dephosphorizing period. This difficulty may be overcome when the Author's method of working the process in two furnaces is adopted—the proportion of lime or limestone added in the first furnace being kept below that required for perfect dephosphorizing, with the result of producing a slag high in phosphoric acid and silica, but comparatively free from iron which, in consequence of its composition, contains a high percentage of phosphoric acid soluble in citric acid as required for fertilizing purposes. The method has been adopted with a series of charges, the details of which are given. The pig-iron

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[1] Two illustrations are given of this motor, together with an account of the experiments in *La Nature*, 15 October, 1898, p. 305.

treated contains from 1·6 per cent. to 2 per cent. of phosphorus, which is reduced by the addition of 18 per cent. to 22 per cent. of limestone and 16 per cent. to 25 per cent. of ore (Swedish magnetite and pyrites residues) to between 0·25 per cent. and 0·70 per cent., while the resulting slag contains from 16 per cent. to 22 per cent. of phosphoric acid, 16 to 21 per cent. of silica, and only 4·68 per cent. to 7·68 per cent. of iron. In the second furnace, by a further addition of 9 per cent. of limestone, the steel is finished, giving a slag with 9 per cent. to 11 per cent. of phosphorus, but in much smaller quantity—the proportion of the first being 21·7 per cent., and that of the second 8 per cent., of the weight of the metal charged. By comparison with the results obtained in several establishments working the basic Bessemer process, it appears that for equal richness in phosphoric acid there is a larger production of slag with a smaller addition of lime in the open-hearth furnace than in the converter. This is due to the large loss of phosphorus by volatilization which in a hot blow may be as much as 30 per cent. or 40 per cent., as well as to the mechanical loss of lime carried away by the blast in the latter method. Comparing the quantity and value of the two kinds of slags, the Author considers that there is an advantage of between 1*s.* 8*d.* to 3*s.* per ton of finished steel in favour of the open-hearth method; and this may be largely increased by using the more phosphoric Swedish magnetites instead of the purer kinds in the first furnace. Thus with ore of 1·2 per cent. of phosphorus it would be from 3*s.* 3*d.* to 4*s.* 7*d.*, and with 3 per cent. of phosphorus 6*s.* to 7*s.* 3*d.* per ton of steel better than with the basic Bessemer process, without taking into consideration the extra yield due to the reduced iron.

H. B.

An Improvement in Open-Hearth Steel-Making.

(Stahl und Eisen, vol. xviii., 1898, p. 714.)

At the Alexandrovski works in Southern Russia a modification of the Siemens ore process was introduced, in 1894, by Mr. Gorjainow. The ore, a hæmatite from Karnowatka containing Fe_2O_3 87·32 per cent., SiO_2 7·70 per cent. and Al_2O_3 2·87 per cent., is mixed with 17·6 per cent. of dolomite and melted down in an open-hearth furnace, the mixture being easily fusible at about 500° or 600° C. Melted cast-iron is then run in, and a violent reaction takes place between the carbon of the metal and the oxygen of the ore, the effervescence being so great that the capacity of the furnace must be about four times that of an ordinary open-hearth furnace worked in the usual way. The operation is very much shortened, the charge being finished in 6 hours instead of 12 hours, and the consumption of scrap is considerably reduced. The furnace-bed is made of lumps of chromic

iron ore, the joints being filled with a grouting of iron ore and lime. The yield in sound ingots is from 76 per cent. to 80 per cent. of the material charged, and the loss by oxidation from 12·6 per cent. to 16·5 per cent. Trials of the method have also been made at Nadjeshidinsk works in the Ural with an ore similar in composition to that of Karnowatka, about 40 per cent. of lime being required, as it is rather siliceous, about 24 per cent. of ore is necessary for the complete decarburizing of the pig-iron. As the blast-furnace was not at work the metal was added cold to the mixture of lime and ore, which was rendered perfectly fluid in 1 hour and 10 minutes. In this way the reaction, which begins as soon as the first portion of the ore is melted, is less violent, and a smaller furnace can be used than with direct metal from the blast-furnace. The largest proportion of ore used was 30 per cent. of the weight of the pig-iron, and 16·38 per cent. of dolomite, of which amount 12·28 per cent. was required for fluxing silica and 3·9 per cent. for alumina.

H. B.

New Forms of Heating Furnaces at Witkowitz, Moravia.

(Stahl und Eisen, vol. xviii., 1898, p. 988.)

These furnaces have been introduced by the inventor and manager of the works, Mr. Pietzka, for heating steel ingots and armour plates at Witkowitz. They are intended to combine the advantages of the Siemens system with a simpler form of construction by continuous heating without reversal of the direction of flame. The working part of the furnace between the fire-place and the flue-end is made movable by mounting it on a central pivot forming the ram of an hydraulic press, so that when lifted clear at the ends it can be turned half round when it is desired to bring the work charged at the flue-end into the hotter region near the fire-bridge. Gas firing is used, the coal being gasified in two producers 3 feet 9 inches square and 8 feet 4 inches deep, with forced draught produced by a Körting aspirator worked with air at 45 lbs. pressure instead of steam. The gas, delivered at a heat of about 900° C., is burnt by air previously brought to a strong heat by passing it through a "recuperator" formed of fire-clay pipes of square section, arranged in two blocks each of 120 pipes in the flue leading to the chimney, which is placed at right angles to the body of the furnace. A further portion of the waste heat is intercepted by a boiler placed between the recuperator and the chimney. The furnace-bed, rectangular in form, is 16 feet 6 inches long and 8 feet 3 inches broad, with two working doors at opposite ends of the long sides, which serve for charging and drawing alternately at each reversal. The central hydraulic pivot is 22 inches in diameter. The consumption of coal is 56 cwt. per shift of

12 hours for a production of 12 tons when in use for welding wrought-iron piles, or 22 tons when reheating steel blooms of 3½ cwt. to 4 cwt. for the finishing rolls.

A furnace of the same class is used for reheating armour plates between the forging-press and the rolling-mill. It differs principally from that previously described in the arrangement of the recuperators, which are in line with the long axis of the furnace. There are three gas-producers, each 4 feet square and 9 feet 6 inches deep; and the recuperators, arranged in two rectangular blocks, contain 1,620 feet of clay pipes, giving a heating-surface of about 1,800 square feet. The furnace-bed, 29 feet long and 13 feet 3 inches broad, is carried by a plate-frame somewhat similar to a locomotive turntable upon a central ram 43 inches in diameter, the overhanging ends resting upon stops when the furnace is in position. There are four charging-doors, with a clear aperture of 32 inches square on the long sides, which are opened and closed by racked rods and pinions like those of the Bessemer converter. The coal consumption is 6 tons in 12 hours when heating a pressed armour-plate block of 30 tons, which requires about 24 hours to bring it up to the proper temperature for the rolling-mill.

H. B.

The Electric Driving of Accessory Machinery in Rolling Mills.

MAX MEIER.

(Stahl und Eisen, vol. xviii., 1898, p. 1028.)

In a new girder rolling mill at Micheville Villerupt electric motors have been adopted for working the live roller trains of the mills, the charging cranes for heating furnaces, saws and finishing machines, carriers to the hot beds, and the machinery in the roll turning and fitting shop. The mills, which are arranged with their axes in the same transverse line, include a cogging mill with a clear length of 38 metres to the hydraulic bloom shear, and four roughing and finishing trains driven by a three-cylinder reversing mill at one end of the line, the cogging-mill engine being similarly placed at the other end. The power produced in a central station by three 250-HP. tandem compound condensing engines, directly coupled to the dynamos and making 85 revolutions per minute, giving a current of 450 volts tension, is distributed to the different motors in the following manner:—

An electro-motor, of 110 HP., drives the bloom feeding rolls and the front and rear part of the girder mill. A second, of 150 HP., adjacent to the large three-cylinder mill engine, drives the feed rollers of the third and fourth pairs of the mill and the carriers for shifting the work sideways from the roughing to the finishing pairs. The two saws are driven each by an electro-motor of

80 HP., and their roller trains on either side by one of 60 HP., and the carriers to the hot beds are served by another of 75 HP. Besides these the fan blowing the gas-producer takes 25 HP., a billet shear and delivery train 75 HP., and the cold finishing machines 150 HP. In addition to these there are two of 60 HP. in the roll turning shop. In all cases the grouped machines are driven by belts from the electro-motor and the reversing is done by hand-gear. The power actually consumed by these machines during the working of the mills varies very considerably. With a constant tension of 450 volts the amount of current varies from 30 to 200 amperes, or from 18 HP. to 122 HP. Detailed examples are given of observations made during the rolling of joists 9 inches high from blooms weighing 30 cwt., requiring an average time of 327 seconds for passing through the mill.

DYNAMO No. 1.—DRIVING THE TRAVERSERS AND DELIVERY ROLLERS OF THE FINISHING TRAIN.

Working.	Tension.	Current.	Time.	Power Exerted.	
	Volts.	Amperes.	Seconds.	Kilowatts.	HP.
Empty	450	30	214	13·500	18·342
Loaded	450	60	12	27·000	36·684
„	450	80	39	36·000	48·913
„	450	100	10	45·000	61·141
„	450	150	17	67·000	91·712
„	450	200	35	90·000	122·282
DYNAMO No. 2.—DRIVING THE FEED-ROLLERS OF ROUGHING TRAIN.					
Empty	450	25	172	11·250	15·285
Loaded	450	80	8	36·000	48·913
„	450	100	38	45·000	61·141
„	450	125	110	56·250	76·426
„	450	150	4	67·500	91·712
DYNAMO DRIVING THE CARRIERS TO THE HOT BEDS.					
Empty	450	12	236	5·400	7·337
„	450	50	46	22·500	30·600
„	450	75	27	33·750	45·679
„	450	150	18	57·500	91·712
DYNAMO DRIVING A HOT SAW.					
Empty	450	10	236	4·5	6·114
Loaded	450	75	50	35·75	45·855
„	450	80	14	36·00	48·913

From five to six saw-cuts are made through each bar, each consuming about 75 to 80 amperes for 10 seconds, except in the last two, when the metal has become harder by cooling, and 80 amperes are taken for about 14 seconds.

The maximum current required by all the machines is summed up as follows:—

	Amperes.
Dynamo of 150 HP.	200
„ 110 HP.	125
„ furnace charger	25
„ blowing fan	25
„ one saw	80
„ saw-feeding rolls	100
„ carrier to hot beds	100
„ shearing machine	20
„ finishing department	150
„ roll-turning lathes	60
„ „ „ crane	40
„ small mill fitting lathe	15
„ electric locomotive	50
„ inclined plane	120
„ sundry small motors	25
Total	1,095

The power supplied by the central station under ordinary conditions, with two of the three generators at work, varies between 400 and 700 amperes.

H. B.

The Influence of Arsenic on the Mechanical Properties of Steel.

J. Marchal.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1898, p. 1336.)

Though this subject has already been studied by previous investigators, the results recorded have shown considerable discrepancies, and hence the Author has judged it expedient to undertake further experiments. The steel he employed was obtained on a basic hearth by the Martin process, and he directed his principal tests to ascertain the effect of arsenic on the welding properties of the metal. The manner of taking the samples at the time of running the steel from the crucibles is explained. The Author introduced into the ingot-moulds the necessary quantity of arsenic, and in each case took simultaneous samples of the steel unalloyed for the sake of comparative tests. The mode of analysis is set forth, and the various percentages of arsenic present, from 0·02 per cent. up to 2·75 per cent., together with full analyses of each sample, are shown in a Table. Plain tests and welding tests were made of each sample, except in the case of the highest percentage of arsenic, which would not weld at all. In all cases over 0·2 per cent. it was necessary in welding to employ a flux of borax, sal ammoniac, &c. As the percentage of arsenic rose the tensile strength increased, but the percentage of elongation fell off almost in direct proportion. When a certain limit was reached

the steel broke like cast iron with a very low strain. It seems probable that the arsenic behaves in the same way as aluminium and sets free a portion of the carbon in the form of graphite. Anyhow, this appears to be the case, judging from the texture of the fractures. In conclusion, the Author states that arsenic, when present in the small quantities usually found, does not interfere with the metallurgical uses of the steel. The discrepancies in the results previously obtained are, he thinks, probably due to the other impurities present in the steel, since arsenic would tend to intensify, along with these other substances which might accidentally be included, the defective quality of the metal.

G. R. R.

The Magnetic Properties of Nickel Steel. EUGENE DUMONT.

(Archives des Sciences Physiques et Naturelles, Geneva, vol. v., 1898, pp. 331 and 426.)

In 1889 Dr. J. Hopkinson discovered that steel containing 25 per cent. of nickel is scarcely magnetic until cooled to a temperature of $-40°$ C. After exposure to cold it remains magnetizable at ordinary temperature, and does not revert to its original condition until heated to about 600° C.

In 1897 Guillaume showed that these nickel-steel alloys may be divided into two classes, namely the reversible, which lose their magnetic properties on heating and recover them at the same temperature on cooling, and the non-reversible, comprising alloys containing 25 per cent. or less of nickel which exhibit the phenomena discovered by Dr. Hopkinson. The Author has determined the permeability at temperatures between $-78°$ C. and $+250°$ C. of twelve samples of nickel steel in a field of from 14 C.G.S. units to 50 C.G.S. units. The method employed was that of Ewing.[1] The magnetizing bobbin was wound with bare copper wire, 1 millimetre in diameter with a distance of about 1 millimetre between each turn, the layers being insulated with asbestos paper and powdered asbestos.

For the experiments at high temperatures the coil was enclosed in a hot-air bath, heated by gas; and for low temperatures it was put in a zinc case surrounded by a freezing mixture. The nickel steel was used in the form of wires of from 0·4 millimetre to 1·0 millimetre in diameter. Full details of the experiments are given, and the results are also expressed in the form of curves. The Author arrives at the following general conclusions. An alloy containing 22 per cent. of nickel and 3 per cent. of chromium showed no trace of magnetism even at the lowest temperature. Another alloy of 35·7 per cent. nickel containing chromium lost

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[1] Ewing and Klaassen. *The Electrician*, 15 May, 1891.

its magnetism at 210°, whereas a similar alloy without chromium retained its magnetic properties up to 235° C. The effect of chromium seems to be manifested in this lowering of the temperature of transformation. All the reversible alloys, at an equal distance from the point of transformation, have the same magnetic permeability, and the magnetic permeability increases with the percentage of nickel.

G. J. B.

A Study of Certain Special Steels. By A. Abraham.

(Annales des Mines, vol. xiv., 1898, p. 225.)

This is a long memoir (122 pages), detailing the experiments carried out by the Author on behalf of the French naval authorities upon certain special alloy steels made at the Imphy works, containing nickel, chromium and silicon in high proportions. The most important of these, known as NC4, has the following average composition:—

Carbon	0·55 to 0·80
Silicon	0·20 „ 0·50
Manganese	0·30 „ 0·60
Chromium	2·00 „ 3·00
Nickel	20·00 „ 25·00

Tested after forging, without special treatment, the elastic limit exceeds 31 tons, and the ultimate tensile resistance 44½ tons, with an elongation of 45 per cent.; but in this condition the flexibility is deficient, so that it is better to subject it to water hardening from a cherry-red heat without further tempering, in which state the elastic limit is reduced to between 19 and 22 tons, but the elongation is increased to 60 per cent. As this elongation takes place over the entire length of the test-piece, the Author considers that objects subject to irregular shocks and strains, such as the steering tillers of large ships, might if made of the alloy be sensibly lighter in section than in soft steel. In thin plates of 2 to 8 millimetres thickness it seems to be well suited for the hulls of torpedo-boats, especially as the waste by corrosion is considerably less than with ordinary soft steel. It may also be used for deck-armour plating, although when subjected to direct attack the resistance was below that obtained with ordinary steel armour.

Forgings in NC4 generally have a rough surface, and it is necessary to take a cut of not less than 10 millimetres in finishing. The metal is therefore only suitable for objects which can be brought to shape by planing or turning alone.

The second class of steel noticed, also made at Imphy, called N 12·5, containing nickel 12 to 12½, chromium 0·75 to 1·0 and carbon 0·3 to 0·45 per cent., is much harder, but can scarcely be used in the natural state as it breaks almost without stretching; but when annealed in a fire of flaming wood it gives a material

suitable for forgings requiring high tenacity and elasticity, the elastic limit exceeding 51 tons and the ultimate strength 63½ tons. In thin plates it is suited for bullet-proof shields and light armour. The properties of alloys of iron and nickel with high proportions (25 to 45 per cent.) of the latter metal have been studied by Mr. C. E. Guillaume, the most remarkable of them being that with 36 per cent. of nickel. This is almost untarnishable in the air, and may be exposed to a saturated atmosphere for months without rusting, and its coefficient of dilatation between 0° and 80° C. is only 0·8 micron (1 micron = 0·001 millimetre), while that of iridio-platinum, such as is used for the international standard metre, is 8 microns. This alloy is therefore admirably suited for making standard bars and similar divided objects where great precision is required.

The last alloy noticed is the silicon steel of Imphy, which contains—

Carbon	0·26 to 0·43
Silicon	1·52 „ 1·65
Manganese	0·63 „ 0·82

This has for some years been employed in the manufacture of high-class springs for railway use. It is rolled into flat bars varying from 60 by 5 to 150 by 12 millimetres, which are heated to cherry red, cooled down in water to 300° C., reheated in a flaming wood fire and cooled slowly in the air. When tested on 4-inch lengths the limit of elasticity is 70 tons, and the breaking stress 79½ tons per square inch, with 7 to 9 per cent. elongation; the fracture is fibrous. This the Author thinks would be especially well suited for deck armour, but up to the present it has not been possible to get a sound ingot of sufficient size to admit of such an application.

H. B.

The Microscopic Structure of Gold.

THOMAS ANDREWS, F.R.S., M. Inst. C.E.

(Engineering, 30 September, 1898, p. 411.)

The object of this investigation was to find out whether an analogy existed between the micro-segregation of the impurities and alloys in iron on freezing, and those in gold. In iron, the impurities and carbon compounds crystallise out in separate areas, which are interspersed throughout the matrix of pure iron. The latter, having a higher fusion point, forms distinct crystals at an earlier stage of the cooling. About 14 ounces of chemically pure gold was cast in a carbon mould, and gradually cooled. A transverse micro-section was prepared, etched, and examined microscopically. The gold was found to have solidified in large crystals, radiating from the centre of the bar. These primary crystals

were further subdivided into smaller secondary crystals, which in turn consisted of a minute tertiary system of crystalline particles of the regular cubic character. A longitudinal miro-section showed primary crystals of a generally hexagonal type, which were further subdivided into a smaller system of secondary crystals. A Table is given, showing the dimensions of primary, secondary, and tertiary crystals.

A. P. H.

Cost of Chlorination at the Alaska Treadwell Mill.

(Engineering and Mining Journal, vol. lxvi., 1898, p. 272.)

The Alaska Treadwell Gold Mining Company, at its mill on Douglas Island, Alaska, saves, by concentration from the stamp-mill tailings, a certain quantity of pyritic residues carrying gold, which is not saved by the ordinary amalgamation. These concentrates are subsequently treated by roasting and chlorination, and the yield amounts to 34 per cent. of the total bullion output. In the year ending 31st May, 1898, the stamp mill treated 254,329 tons of ore; and from the tailings 4,331·7 tons of pyritic concentrates were saved. The cost of saving these was 16*s*. per ton of concentrates, or 2½*d*. per ton of ore treated. The cost of chlorinating the concentrates was 16*s*. per ton for labour and 15*s*. 5*d*. for supplies, the total cost being £1 11*s*. 5*d*. per ton. The actual net consumption per ton of concentrates treated was 57·60 lbs. of acid, 17·35 lbs. of oxide of manganese, 151·44 lbs. of salt, and 8·25 lbs. of scrap iron. The cost of fuel (wood and coal) was 4*s*. 11*d*. per ton. The average return obtained from the concentrates in gold was £8 17*s*. 5*d*., and as the cost of saving them from the tailings and of treating them amounted to £2 7*s*. 5*d*., the profit on the work was £6 10*s*. per ton.

B. H. B.

Signalling to Great Distances by means of Free or Captive Balloons. DIBOS.

(La Revue Technique, 1898, p. 489.)

It is pointed out that the importance is now generally recognised, especially in war time, of aerial communications capable of being made out at great distances. For this purpose the use of balloons, fitted with an apparatus for the emission of a powerful light, which can be used without encumbrance and without danger, would seem to be eminently suitable. Reference is made to some experiments conducted at Toulon in 1878, when rockets lighted at a height of 2,296 feet above the sea were visible in a clear state

of the atmosphere at two observatories distant respectively 36 miles and 47 miles from the spot, and even in one case they were visible at no less than 90 miles. The danger of naked flames at or near to a balloon is insisted upon, and it is stated that, as the result of experiments, a distance below the car of 33 feet is sufficient to avoid all risks, but 66 feet is here assumed for greater precaution. The Author's system of producing an intense light by means of calcium phosphide in a vessel of water suspended below the balloon is explained by reference to a diagram. The water is supplied at the time the light is required by passing it down an india-rubber tube from the car of the balloon. The light produced in this way is intensely vivid, resembling that of magnesium or the electric arc, and it cannot be extinguished by wind or rain. A charge of from 14 ozs. to 16 ozs. of the calcium phosphide will burn for 30 minutes to 45 minutes.

G. R. R.

The Telegraph Cables of the World.

(Archiv für Post und Telegraphie, 1898, p. 193.)

This article gives a list of the number and lengths of the various telegraph cables throughout the world. These are set forth in two Tables, the first showing the particulars of those belonging to the several Governments, and the second those owned by private companies. It appears that in the year 1894 the total length of cables was 181,414 miles, while for the year 1897 the length is given as 187,196 miles, showing an increase of 5,782 miles. Of this increase 1,550 miles belongs to Germany. In the first Table 33 countries are quoted, owning 1,141 cables, of a total length of 22,831 miles; and in the second Table 30 companies are named, owning 318 cables, with a total length of 164,366 miles.

E. R. D.

Wireless Telegraphy. SCHLUCKEBIER.

(Archiv für Post und Telegraphie, 1898, pp. 208–240. Figs.)

The wire has hitherto been an essential part of telegraphic apparatus, but is costly and a constant source of trouble. The Author remarks that projects for wireless telegraphy are not new, as various experiments were described in the Archiv between 1892 and 1895. He cites those experiments made between the coast of Scotland and the Island of Mull, and refers to Marconi's very recent inventions. Before dealing with these, however, he gives particulars of experiments carried out at Berlin in 1894–5 by means of high potential currents passed into the earth. The

apparatus employed are shown by figures in the original text. The primary current passes through a conductor provided with an earth plate at each end. Two other plates at a distance from the first pair are connected by a conductor, through which passes the current received by those earth plates; the current received is, of course, only a small fraction of that passing between the first pair of plates, but is sufficient to actuate a telephone receiver. Alternate currents would serve, but as the usual periodicity is only about fifty per second, it was found better to employ a direct current dynamo with a battery in series and a rotary make and break apparatus to give several hundred vibrations per second. A key is used to send the Morse code. The two conductors should be parallel. The experiments referred to were carried out by Mr. Rathenau in Berlin near the Wannsee Railway station. Two zinc earth-plates, each of 32·4 square feet area, were buried in the bank of the lake 545 yards apart and connected by insulated copper wire. Current at 100 volts was obtained from the public supply and fifty large cells connected in series. Current of 2 amperes to 3 amperes was used, with 500 to 600 breaks per second. The secondary wire was carried in a boat, and zinc plates of 21·6 square feet area used at a distance of 90 yards to 110 yards apart. Satisfactory results were obtained up to a distance of 2·5 miles.

Earth tests were also made near Nauen, and gave satisfactory results at a distance of 3·53 miles. Further experiments were made in the neighbourhood of electric railways, and the effect was observable to a distance of 1·86 mile. A current of 16 amperes in the primary enabled messages to be sent through the earth a distance of 10·5 miles. The Author then gives a description of the Marconi apparatus and the results obtained.

E. R. D.

Construction of Ice-Breakers.

R. Runeberg and Admiral C. Makarov.

(Morskoi Sbornik, October, 1898.)

The Author, who has given special attention to this subject for many years, refers to a Paper he communicated to the Institution of Civil Engineers, "On Steamers for Winter Navigation and Ice-breaking,"[1] in which he investigated, theoretically, the proper form for the bows of such vessels. Experience with ice-breakers, built since that time, has enabled him to test the accuracy of his views, and has induced him to modify them to a certain extent. He points out that the two principal points about the form of the bows of such vessels are (1) that they should have hollow

[1] Minutes of Proceedings Inst. C.E., vol. xcvii., p. 277.

water-lines so as to let the stem cut and split the ice, and (2) that the buttock lines should enter the water at a mean angle with the horizontal of from 21° to 30° as a maximum. He explains that with such bows the ice-breaker cracks the ice with the stem, and then rises on to it and breaks it down by its own weight, and shoves it away sideways and downwards. He discusses the value of the spoon-bow, and the angle which the sides of the vessel should form with the vertical, and mentions several recently constructed successful ice-breakers, including the one for the new port of Libau, and alludes to the one for ferrying the train across the Baïkal Lake, and the powerful one called "Ermack," with 10,000 I.HP., now in course of construction by Messrs. Armstrong, Mitchell & Co., intended to keep the passage clear through the Cara Sea in summer, for navigation to and from the Enisëi river, and to keep open the channel to St. Petersburg in winter.

There are a great many ice-breakers at work in different parts of Russia, and the Author is glad to find that his views concerning their form have been gradually adopted more and more; but he regrets that they have not yet been carried out in their entirety.

Admiral Makarov contributes some remarks differing on some points from Mr. Runeberg, especially with regard to the Arctic Ocean ice-breaker "Ermack." He also makes some interesting remarks about the importance to Russia of extending the use of ice-breakers, so as to increase the duration of the navigation of their extensive waterways all over the empire.

C. H. M.

Danish Ice-Breakers and Railway-Train Ferries.

N. Afanassiev.

(Morskoi Sbornik, November, 1898.)

Referring to a Paper by Captain Tuxen, on "Danish Steam Railway Ferries and Ice-Breaking Steamers," read at the International Naval Architects and Marine Engineers Congress of 1897, in London, the Author says his Paper is really supplemental to that one. He begins by giving some particulars of such vessels built by Armstrong, Whitworth & Co., viz., a train-ferry steamer and separate ice-breaker for Saratov, on the Volga; a combined ferry and ice-breaking steamer for the Siberian railway to cross the Baikal lake; an ice-breaker for Finland; and the largest ice-breaker yet made for use in the Kara Sea. All these have one screw propeller at the bows (besides others aft) which is found useful in breaking up the ice.

Then follows what is practically a reproduction of Captain Tuxen's Paper.

The Author then discusses the proper lines for the hull and trim of the vessel; it should be short, with the largest cross-section

well forward of midships, giving a fine run aft, so as to allow the ice which has been forced down by the bows to float up before reaching the propeller, and with a spoon bow; the draught should be much greater aft than forward, and large water-ballast tanks are required at each end of the vessel to adjust the trim according as the vessel is going ahead or astern. He explains various special arrangements about the machinery to meet the exceptional requirements of the work these vessels have to perform.

C. H. M.

Petroleum Fuel for Vessels of the Russian Navy and Volunteer Fleet. N. Cherkassov.

(Morskoi Sbornik, July, 1898, p. 129.)

The object of this article is to demonstrate the importance of the use of petroleum fuel for the Russian fleet. Thus far it has been found, in workable quantities, only on the northern slope of the Caucasus Range; but there are indications of it on the southern slope also, towards the Black Sea. The Baku district yields 400 million poods (6,450,000 tons), and the other districts 50 million poods (800,000 tons) per annum, and the yield is continually increasing.

The Author suggests that 10 per cent. of the total yield should be contributed annually to the Government, by way of impost, to secure a supply of fuel of 40 to 50 million poods (650,000 tons to 800,000 tons) a year for the navy.

The use of petroleum fuel dates only about 17 years back. Now all the steamers on the Caspian (about 200) and all those on the Volga (about 1,000) use it, as well as most Russian railways and most of the works in the basins of the Volga, Kama and Oka. The total consumption of petroleum as a fuel has reached 300 million poods (4,840,000 tons) per annum. The Black Sea fleet could be supplied by direct pipe-lines, and for the supply of the Baltic fleet, the Government should form depôts at suitable places along the Volga, which would be supplied by water-carriage from the Caucasus, and from which the oil could be conveyed to St. Petersburg and the Baltic ports by rail or water-carriage. This would make Russia independent of any other country for the fuel supply for her fleet at home; whilst when the vessels are out of reach of petroleum, the furnaces could readily be changed for the use of coal fuel. The trials, hitherto made with petroleum as fuel on vessels of the Russian navy, have not been successful, because they were not properly carried out.

The crude petroleum of the Caucasus, which is called raw naphtha in Russia, has a specific gravity of 0·75 to 0·925, and consists of 86·87 per cent. of carbon, 12·19 per cent. of hydrogen, 0·88 per cent. of oxygen, and 0·06 per cent. of sulphur, besides

very minute quantities of lime, oxide of iron, alumina, copper, and traces of silver and gold. The products of distillation are, first, 4 per cent. to 5 per cent. of benzene, which is useless for burning; then 30 per cent. to 35 per cent. of the ordinary kerosene of commerce, leaving a residue of 60 per cent. to 65 per cent., which is called astatki (meaning residue) or mazoot, and which forms the ordinary petroleum fuel. This is commonly called naphtha in Russia, in contradistinction to raw naphtha or crude petroleum. The demand for this fuel is increasing more rapidly than its production, so that the price is going up, and it will soon become necessary to use crude petroleum as a fuel, either mixed with astatki, or by itself; and the Author considers it will soon become a regular practice to prepare crude petroleum for fuel, by heating it, to drive off some of its more volatile compounds. Crude petroleum may be used with perfect safety, even without previous heating. Fresh crude petroleum at Baku does not ignite at a lower temperature than 25° C. (72° F.); after a short exposure to the air this temperature rises to 40° C. (104° F.); after a week's exposure, to 60° C. (140° F.); and after a fortnight's exposure, to 70° C. (158° F.). The temperature of ignition of astatki varies from 80° C. to 170° C. (176° F. to 338° F.), according to the amount of distillation it has undergone. As a matter of fact, about 20 million poods (322,000 tons) of crude petroleum, taken from the tanks at the wells, are now consumed annually at Baku, by the locomotives on the local railways and in the furnaces of most of the works' boilers in the place, without any accidents. The regulations laid down by the Russian Technical Society, in 1882, and which are still in force, are given by the Author. According to these, the use of any liquid fuel, with a flashing point below 56° R. (158° F.), is forbidden. These regulations apply to crude petroleum as well as to astatki.

The Author deals with the properties of coal and petroleum as fuels in considerable detail, and summarises the advantages of petroleum over coals for the Russian navy, as follows: (1) economy; (2) speed, cheapness, simplicity and cleanliness of loading fuel; (3) reduction of the number of stokers and of labour generally; (4) absence of ashes or clinkers; (5) continuous and uninterrupted firing; (6) facility of management of the fires; (7) speed with which steam can be raised in case of need; (8) absence of sparks or smoke; (9) the form of the flame can be varied to suit the shape of the furnace; (10) economy of space, and facility of storage and transport; (11) complete combustion without residue; (12) less heat and more air in the stokeholds; (13) facility of checking quantities received and consumed.

Although the actual cost of petroleum fuel is somewhat greater than that of coals, wood, or turf, on most of the railways on which it is used, as well as in most works in St. Petersburg, Moscow, and the manufacturing districts, yet its advantages in other respects are so great that its use is spreading in all directions and increasing from year to year.

C. H. M.

Oil v. Soap-and-Water for Calming Broken Waves.

GERHARDT.

(Centralblatt der Bauverwaltung, 1898, p. 355.)

A short account of some experiments made at sea by Captain Gathemann of the North German Lloyd steamship "Oldenburg" to determine the respective effects of oil and soap and water on a heavy and broken sea. The soap and water was composed of 7·5 kilogrammes (16·5 lbs.) of green soap to 40 litres (8·8 gallons) of water. The "Oldenburg" is 132·6 metres (435 feet) long, and the oil or soap and water was dropped from the forward water-closets, 24 metres (79 feet) from the stem, when the ship was travelling at a speed of about 12·5 knots. The oil used amounted to about 1·25 kilogrammes (2·7 lbs.) per hour and was most effective; the soap and water, contrary to the results of Professor H. Köppen's experiments, proved quite useless.

W. B.

The Sparking of Commutators.

H. F. PARSHALL, M. Inst. C.E., and H. M. HOBART.

(Engineering, 16 September, 1898, p. 349.)

Great improvement has recently been made in the sparkless collection of commutated currents, with constant position of brushes. Radial bearing carbon brushes are now extensively used, while the commutator segments are insulated by mica, wearing at the same rate as the copper, and remaining even therewith. The avoidance of sparking depends on an understanding of armature interference. In the formula

$$E = K\,T\,M\,N\,10^{-8},$$

T and M must have such relative values as to fulfil the necessary conditions for sparkless collection of the current and regulation of the voltage with varying load. The brushes must be so placed that each coil, when in contact therewith, shall be in a magnetic field of the direction and intensity necessary to reverse the current it has just been carrying. Under such conditions there is no sparking. But as the current output is increased, a stronger field is necessary to reverse it, while this stronger current so magnetises the armature as to distort the field, and weaken the magnetic flux. The shifting of the brushes further intensifies the demagnetising effect of the armature. Finally, a current output is reached at which sparkless collection is impossible. Experiments have been made to ascertain the distribution of the magnetic flux in the gap

by means of an exploring coil. The excitation of the field was maintained constant. Curves are given showing the distribution of flux with various positions of the brushes, which show that the total magnetic flux, as represented by the area of the curve, is the same with no current in the armature as with the full load current with the brushes at the neutral point. The distribution is, however, different.

A. P. H.

The Multiple-Resonance of Electrical Oscillations. L. DECOMBE.

(Archives des Sciences Physiques et Naturelles, vol. v., 1898, p. 121.)

The Author has photographed, by means of a revolving mirror, the discharge of a condenser made as follows: Twelve plates of brass, 15·7 centimetres by 28·9 centimetres, were fixed parallel to one another 2 centimetres apart. A brass bar on each side connected the alternate plates, and the whole was immersed in a bath of oil. Two solenoids of brass wire 4 millimetres thick connected the condenser with the spark-gap, which consisted of two adjustable spheres in a glass vessel filled with vaseline oil, beneath the surface of which the spark was taken. The revolving mirror made from 400 revolutions to 500 revolutions per second.

The photographs show about fourteen oscillations. On careful measurement with a dividing engine the oscillation period was found to be constant throughout the entire duration of the discharge, disproving the hypothesis of Swyngedauw, according to which the heating effect of the spark should cause a diminution of the period, and confirming Feddersen's experimental proof that the period is independent of the resistance.

G. J. B.

The Earthquakes of the United States.

F. DE MONTESSUS DE BALLORE.

(Archives des Science Physiques et Naturelles, vol. v., 1898, p. 201.)

The Author has collected statistics of 5,121 earthquakes in 588 localities, which he has grouped together in 14 districts. With the exception of the New England district, for which the data go back to 1725, most of the records relate to the last 50 years. Under each district he gives the names of the localities, with the number of earthquakes in each, and the Paper is accompanied by a map in which the relative seismic activity of the various regions is indicated.

G. J. B.

Stress-Strain Relations of Rubber. R. H. Thurston.

(Science, vol. vii., 1898, pp. 522–523.)

The Author refers to some earlier work, and then says: "In all cases the substance behaved under load precisely as do other materials in the early part of its strain; then a reversed curve is described, and the test-piece stiffens greatly, and offers continually increasing resistance until at last rupture takes place, without yielding by inelastic deformation at any point of its course. Toward the end of its test the substance yields proportionately to the applied load. The fracture is sharp and without warning, and the break clean and smooth, and at right angles to the line of pull. No permanent reduction of section is observable after fracture. The reduced section immediately before breaking is but one-eighth the initial section of the unstrained rubber. Permanent set occurs to an exceedingly slight extent, and its value is dependent upon the maximum load, and independent of the elastic properties of the substance. The set of the material would not be noticed in ordinary use. Permanent loads produce permanent continuous extension, and in time fracture. This was found to be true for loads rising from 40 lbs. to 330 lbs. per square inch (2·8 to 23·18 kilograms per square centimetre), and stress-strain diagrams for two weeks showed steady elongation.

"Plotting curves having for their co-ordinates loads per unit of area and areas of section of test-piece at point of maximum reduction, the stress-strain diagram thus produced becomes altered in form, and similar to those of other materials plotted in the usual manner. It has the same curvature at the initial stage, the same straight line to an (apparent) elastic limit, and finally a steady but slight rise with increasing loads, with a sudden break at the end. The highest load measured in these experiments was 810 lbs. per square inch (56·7 kilograms per square centimetre). The quality employed in all cases was that of the stationer's elastic bands."

The Author concludes with a reference to R. A. Fessenden's explanation of the observed phenomena.

A. Gs.

Corrected Value of Rowland's Measurement of the Mechanical Equivalent. W. S. Day.

(Physical Review, vol. vi., 1898, pp. 193–222.)

The Author has compared three of Rowland's thermometers directly with three Tonnelot thermometers which had been completely studied at the Bureau International (two of which were broken in crossing the Atlantic). The Tonnelot thermo-

meters were used exactly according to the directions given by Guillaume, in a specially constructed water-bath, which is described in detail. The Rowland thermometers could not conveniently be used vertically, as Rowland himself used them, but their pressure-coefficients were determined, and correction made for the difference of position. The treatment of them with regard to zero-point was the same as Rowland adopted. The thermometers, when corrected to the absolute scale according to Rowland's tables, showed differences from the Paris hydrogen scale amounting to 0°·032 as a maximum. Rowland's values for the equivalent are recalculated accordingly, and the results given for each degree from 6° to 36°. The following is an abstract:—

Temperature. °	J.
6	4·203
10	4·196
15	4·188
20	4·181
25	4·176
30	4·174
35	4·175

The minimum occurs at 31°·5. $J = 4 \cdot 2 \times 10^4$ at 7°·5.

The temperature-coefficient agrees well with Griffiths' values from 15° to 25°. The absolute values are less than Griffiths' by $\frac{1}{300}$, and less than Schuster's by $\frac{1}{400}$; the discrepancy is almost certainly not due to thermometric difficulties.

An abstract of the work occurs in the Philosophical Magazine, August 1897, but it contains an error.

R. A. L.

Mechanical Equivalent of Heat. J. B. BAILLE and C. FÉRY.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxvi., 1898, pp. 1494–1496.)

A copper cylinder is placed in a rotating magnetic field, produced by surrounding the cylinder coaxially with a ring, to which, in a suitable manner, a two-phase current is supplied. The cylinder tends to rotate, but is prevented, the couple being measured by a balance. The frequency of the current is known, and the work spent on the copper can therefore be readily calculated. The rise in temperature of the cylinder is measured by a thermometer placed in a cavity, cooling corrections being applied. The values of the mechanical equivalent obtained vary from 422 to 426. The work is to be repeated with improved apparatus.

A. Gs.

Universal Shunt. J. Rymer-Jones.

(Electrical Review, vol. xlii., 1898, pp. 717–718.)

The Author, in view of the incorrect opinion that Kelvin-Varley slides are not applicable as a universal shunt, gives calculations showing that the scale-reading is proportional to the multiplying power of the shunt. He then describes a simplified form of Kelvin-Varley slides, in which the 100-vernier coils are fixed to a movable ebonite disk, to which also are fixed the springs making contact with the main resistances. For the rough adjustment the whole disk is moved round, and the same handle serves, on loosening a detent, for the fine adjustment with the vernier coils.

G. H. Ba.

Conductivity of Gases. R. W. Wood.

(Physical Review, vol. vi., 1898, pp. 165–166.)

A compact apparatus of the kind devised by Kuntz is described, for showing the conductivity of gases. A larger bulb containing the gas to be tested (or a vacuum) surrounds a smaller bulb containing ether and communicating with a nozzle. On immersion in boiling water, the ether is more or less rapidly evaporated according to the conductivity of the intervening gas, and the vapour will burn at the nozzle in a jet of corresponding height. The bad conductivity of a vacuum is well shown. Glass-working directions are given.

A. D.

Determination of Thermal and Electric Conductivities. P. Straneo.

(Roma, R. Accad. Lincei, Atti, vol. vii., 1898, pp. 197–202.)

A mathematical Paper showing how it is possible, by simultaneous observations, to ascertain both the thermic and the electric conductivities of a wire at high temperatures. The error due to slight mismeasurements of the points at which certain stationary temperatures are observed is very small.

A. D.

Cadmium Standard Cell. P. Kohnstamm and E. Cohen.

(Annalen der Physik und Chemie, vol. lxv., 1898, pp. 344–357.)

The Weston cadmium cell shows an irregularity in the temperature coefficient below 5°, which renders its use in the cold less satisfactory. The Authors investigate the cause of the irregularity, and discover it in the fact that the curve of solubility of the cadmium sulphate undergoes a sudden change at 15°, remaining stationary between that temperature and 20°. This is no doubt due to some change in the constitution of the salt, which under ordinary circumstances corresponds to the formula $CdSO_4 \cdot \frac{8}{3}H_2O$. This change is analogous to the change of crystalline form undergone by sulphur at 95°. The Weston cell should only be used at temperatures above 15°. It then is much more stable than the Clark cell.

E. E. F.

Fifth Annual Report of the Committee on Atomic Weights. F. W. Clarke.

(Chemical News, vol. lxxvii., 1898, pp. 239-242.)

Papers published during 1897 which bear on atomic weights are critically reviewed. The Papers considered refer to the atomic weights of carbon, nitrogen, chlorine, silver, aluminium, nickel, cobalt, tungsten, and cerium. A complete list of atomic weights is given which differs from that published in 1896 in the following instances—carbon = 12·00, cerium = 139·35, cobalt = 58·99, when O = 16. Rummel[1] has worked out relationships between the spectra of the alkali metals and their atomic weights, from which the latter may be calculated with fair accuracy.

T. E.

Electromotive Properties of Chromium. W. Hittorf.

(Annalen der Physik und Chemie, vol. lxv., 1898, pp. 320–343.)

The position of chromium in the electromotive series depends upon its chemical state. Fresh fractures of the metal are in an active state, corresponding to the oxide CrO_3, and in that state the metal stands immediately above zinc, and precipitates other metals from their solutions. In the inactive state, corresponding

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[1] Proceedings of the Royal Society of Victoria (Australia), vol. x., part p. 75.

to the oxide CrO, it is a noble metal, reduces no other metal from its salt solutions, and stands at the electro-negative end of the series next to platinum. Experiments with a large number of different electrodes and electrolytes show that chromium as an anode may, with the same electrolyte, assume each of its three grades, according to the solvent and the temperature. By modern processes the metal can be obtained in large quantities, completely fused and free from carbon.

E. E. F.

Polarization and Electrolysis. Del Proposto.

(Bulletin de l'Association des Ingénieurs Électriques, Liége, 1897, pp. 36–57.)

The Author has investigated certain discrepancies which are found to occur between the observed electromotive force of polarization and the value determined by Kelvin's law, for various solutions. He describes some experiments in which the terminal potential difference and the polarization electromotive force were measured for gradually increasing currents, and obtained curves similar to curves of magnetization, *i.e.*, two substantially straight lines connected by a curve. From this the Author draws the following deductions, viz.:—Assuming that the two ions of the electrolytic molecule are charged with electricity of opposite sign so as to form a kind of elementary electromagnet, then, under the action of the electric force, the small magnets will be turned with their similar poles to the same sides, and the electrolyte will form a kind of magnet which only presents free masses (? magnetism) at the surfaces in contact with the electrodes. The mean intensity of magnetization, which corresponds to polarization in condensers, will be equal to the mean density of electricity on the extreme faces of the electrolyte, and the intensity of the current corresponds to the intensity of the field in the phenomena of magnetization.

The Author also investigated the effect of introducing diaphragms of glass and metal into the liquid between the electrodes, the diaphragms extending to various depths in the liquid. He found that the increase of potential difference for a given current passing through the voltameter follows approximately the same law as the fall of pressure produced by throttling a water-conduit. The Author also discusses the "secondary electrolysis" which is set up when the diaphragm is made of conducting material.

C. K. F.

Secondary Electrolysis. E. ANDRÉOLI.

(Ind. Electrochim., vol. ii., 1898, pp. 36–38; also Génie Civil, 29 June, 1895.)

If an electrolytic cell be divided into three compartments by means of porous partition-walls, and be filled with the same electrolyte, a current passed through it by means of electrodes in the two outer compartments does not produce any change in the central compartment of the cell. If, however, one or more insulated metal plates be immersed in the liquid in the latter, electrolytic decomposition occurs, and to this the Author gives the name of "secondary electrolysis," and states that he is the discoverer of this phenomenon.

As examples of secondary electrolysis he gives the following:—

1. Deposition of gold from a gold-cyanide solution placed in the central compartment, lead plates being used to receive it. In the outer compartments solutions of sodium chloride are used with a gas-carbon anode, and an iron kathode.

2. Deposition of gold from gold-cyanide solution in central compartment.—The outer compartments were filled with the same solution of gold-cyanide, but after many days no change could be detected in the gold contents of the liquid in these compartments.

3. Conversion of sodium bisulphite into hydrosulphite.—The side compartments in this case may contain any electrolyte; the central compartment is fed with a solution of the bisulphite, and only two metal plates are immersed in it. Bleaching operations can be effected by means of the liberated hydrosulphite.

The Author considers that these observations and facts are in conflict with the modern theory of ionic transportation, and he closes his article with a request to electro-chemists for criticisms and suggestions upon the subject.

J. B. C. K.

Electrodes for Electrolysis of Alkali Metal Chlorides.

H. BECKER.

(Ind. Electrochim., vol. ii., 1898, pp. 25–26.)

The materials generally used for electrodes to be employed in salt solutions containing chlorine are gas-carbon, or graphite with which ordinary coke is sometimes mixed to form a moulding compound. High density is one of the chief characteristics required of the product. Girard and Street and Castner convert ordinary carbon into graphite by heating it in closed boxes to the temperature of the electric arc. Other inventors have described electrodes of high resistance towards chlorine, made by moulding mixtures of powdered carbon and tar under pressure, and heating to 1,000° C. The use of rough blocks of gas-carbon, made into one

conducting medium in various ways, has been patented by many inventors. Others have suggested the use of metallic oxides—as, for example, Gerald and Falconer, peroxide of lead, and Blackman, magnetite or ilmenite.

Electrodes formed of an alloy of platinum and iridium are in actual use in several works producing bleach and chlorates. Platinum alone is not found sufficiently resistant to the chlorine; while platinised electrodes are still less satisfactory. The forms of the platinum-iridium electrodes are very diverse. In the chlorate works they are generally made by stretching thin sheets of the alloy over a wire frame of the same. Kellner has patented a form in which short platinum wires are embedded in an ebonite plate. Hoepfner has patented the use of ferro-silicium; but this was previously described by Uelsmann. Parker and Robinson have suggested chromium phosphide. As materials for kathodes, gas-carbon, iron, and nickel are in actual use. Fluid kathodes have been patented by several inventors: Castner and Kellner have used mercury, while Vautin and Hulin have used molten lead. Finally, Richardson and Holland, and Franchot and Gibbs have patented the use of copper oxide. Short descriptions of many of the above patents are given.

J. B. C. K.

Diaphragms for the Electrolysis of the Alkali Metal Chlorides.

H. Becker.

(Ind. Electrochim., vol. ii., 1898, pp. 33–34.)

Many materials for diaphragms have been proposed, but only few have received experimental trial. Parchment-paper has been suggested by Le Sueur, Kiliani, Rathenau and Sutter; it is in actual use at Rumford Falls, U.S.A., and at Bitterfeld in Germany. At Leopoldschall parchment protected by a coating of calcium or magnesium oxychloride is used in the electrolytic cells.

Rieckmann describes diaphragms of albuminised paper, or of albumen alone; while Hoepfner has suggested the use of paper or cardboard coated with collodion. Diaphragms of unglazed porcelain or baked clay have been patented by many, and are in actual use in three works. Asbestos as a material for diaphragms has been patented by Roberts and McGraw, Hargreaves and Bird, Riquelle, Wiernick, Waite, Hempel, Richardson, and by Lucius and Bruning. Porous partition walls of Portland cement have been patented by Breuer, Hurter, and by Carmichael. Brief descriptions of all the patents named above are given by the Author.

J. B. C. K.

Storage-Batteries in America. J. Wetzler.

(Electrical Engineer, New York, vol. xxv., 1898, pp. 443–460.)

This is an illustrated account of the works of the Electric Storage Battery Company, of Philadelphia, and of the processes involved in the manufacture of their storage cells. Particulars are also given of some large batteries installed in central stations, tramway stations and lighting plants, and of their application in telephone exchanges, and for telegraphic purposes. The positive plates, "Manchester" type, consist of a grid of antimonious lead, with coils of corrugated lead tape forced into the apertures under hydraulic pressure. The tape is corrugated, cut into lengths, and coiled by an automatic machine, which does the same work as forty to fifty boys. The negative plates are constructed of pellets or pastilles of cast lead chloride—hence the name "chloride accumulator"—held together by a frame of antimonious lead cast round them. They are then placed between sheets of zinc in an electrolyte of zinc chloride, and the pastilles reduced to a highly crystalline form of porous lead. Finally, they are subjected to several washings and constituted kathodes in an electrolytic bath for some hours, to ensure the entire elimination of chlorine from the pastilles. Both the positive and negative grids are cast under a pressure of 100 lbs. per square inch.

E. J. W.

Variation of Capacity of Accumulators with Discharge Rate. J. Reyval.

(L'Éclairage Électrique, vol. xv., 1898, pp. 143–146.)

W. Peukert found that the current I and time of discharge t are related by the formula—

$$I^n t = k,$$

in which n and k are constants for any particular type of cells. The Author gives an account of the results obtained by F. Loppé in verifying this law. A set of curves is given, showing the marked variation of capacity.

W. R. C.

Lead-Zinc and Cadmium Accumulators.

(L'Éclairage Électrique, vol. xv., 1898, pp. 242–244.)

The use of zinc instead of lead for the anodes of accumulators (*e.g.* that of Regnier) offers the advantages of an increased electromotive force, and also, owing to diminished weight, of an increased specific capacity. Unfortunately, the zinc dissolves when the circuit is open, a defect which is very imperfectly remedied by amalgamation, and hence Commelin and Finot use cadmium instead. In the Werner accumulator, the electrolyte is a solution of the mixed sulphates of zinc, cadmium, and magnesium. In charging, a coherent deposit of zinc and cadmium is obtained, which is practically unattacked when the circuit is open, the magnesium playing a little-understood but most important part. It is found that if a concentrated solution of zinc sulphate is used alone a good deposit of zinc is produced, but the peroxidation of the kathode is feeble; whilst if cadmium sulphate be employed a good deposit and satisfactory peroxidation are obtained, but the electromotive force falls off rapidly during the discharge. On the other hand, with dilute solutions of either salt peroxidation is well affected, but a poor deposit is obtained. The addition of magnesium sulphate allows of the production of all the necessary conditions by means of solutions of moderate strength; nevertheless, it is better to use more dilute solutions for rapid than for slow discharges. Some minor improvements are also made in the construction of the positive plates, with the object of bringing the active material into closer contact with the conducting support. The accumulator has a capacity of 82 watt-hours per kilogram of plates, or 36 watt-hours per kilogram of total weight, the current being 12 amperes to 15 amperes. The electromotive force is 2·4 volts at the commencement, and 1·9 volt at the end of the discharge.

J. W.

Electrical Press-Room.

(West. Electn., vol. xxii., 1898, pp. 221, 222.)

This is an account of the motor-driven presses of the *Chicago Record* and *Daily News.* Each press is driven by two motors, one for driving purposes, and a smaller slow-speed motor to manipulate the press in "making ready." An important feature of this installation is Mr. Stone's electro-pneumatic system of motor-control. Compressed air is used to operate the contact-arms of the rheostats, and at a number of convenient points on each press air-valves and push-buttons are located. The handle of an air-cock controls, through the specially constructed rheostat, the slow-speed motor, which is used in "dressing the press," or in making

ready to run off an edition. This valve is constructed with three inlets and an exhaust, and can be set, first, to run the press slowly; second, to stop the press; or third, to cause the air to go through a by-pass in such a manner that the press cannot be started from any other point.

W. G. R.

Reiter's Speed-Regulator for Turbines.

(L'Éclairage Électrique, vol. xv., 1898, pp. 290–293.)

An illustrated description of H. Reiter's electric brake, for use as a speed-regulator in the case of turbines working under a small or moderate head of water, in which case a difficulty has always been experienced in maintaining a sufficiently constant speed with large variations of load. The device consists of a small centrifugal governor, which, by raising or lowering a mercury vessel, alters the amount of resistance included in the circuit of the brake electro-magnet. The brake itself consists of a fixed central electro-magnet with re-curved pole-pieces, and an outer ring of steel or iron, which is driven by the turbine, and which absorbs more or less power by the eddy-currents induced in it, according to the degree of excitation of the magnet. The regulator is said to be much quicker in action than one in which a hydraulic brake is used.

A. H.

Electric Governor for Marine Engine. E. Putato.

(L'Éclairage Électrique, vol. xv., 1898, pp. 293, 294.)

Two mercury-vessels, attached to a longitudinal wall of the ship, communicate with each other by means of a connecting pipe. As the ship pitches, causing the propeller to rise either partially or wholly out of the water, mercury flows from one of the vessels into the other, the effect being to gradually short-circuit a set of resistances connected to contact-pins, which pass into the space above the mercury contained in the vessel near the bow of the ship. As these resistances are cut out, the current through one of a pair of electro-magnets controlling the main steam-valve increases, and the valve is gradually closed. When the bow of the ship rises, the resistances are gradually inserted, and before the last pin rises above the mercury, an auxiliary electro-magnet closes the circuit of the second large electro-magnet controlling the valve, which is thereby opened. In the normal position of the vessel, no current passes through either electro-magnet.

A. H.

Morrison's Apparatus for Power Conversion.

(West. Electn., vol. xxii., 1898, pp. 277, 278.)

The apparatus constitutes a variable speed-gear designed primarily for horseless carriages; the one in question weighs about 200 lbs., and is of 4 HP. A gas- or oil-engine runs at a constant speed of 600 revolutions per minute, and is regulated by a centrifugal governor. To the shaft is fixed a cylinder carrying field-magnets. Mounted upon the shaft, but free to revolve upon it, is a Gramme ring-armature with commutator. When the vehicle is at rest the armature is stationary, and in starting, after the electric circuit is closed, the greatest current is generated. As the speed of the armature increases, the energy exerted diminishes and the speed of the carriage increases.

A. S.

Belt Driving. J. Tullis.

(Mechanical Engineer, vol. i., 1898, pp. 452–454, 487–490.)

The Author discusses the manufacture and care of leather belts for main-driving. High-speed belts running over 4,000 feet per minute should be made of single, pliable, tough thin leather; by compounding such belts, they may be run with advantage up to 9,000 feet per minute. Compound belt-driving is a simple and most trustworthy means of transmitting power without loss from slip. The cost of a narrow pulley is much less than that of a wide pulley; two 20-inch belts, working compound, will transmit more power than one 40-inch belt working from a wide pulley. The Author gives a number of examples in which compound belt-driving has been applied with satisfactory results. To get perfect belt-driving, a great deal depends on the form of the pulleys. Much loss of power and destruction of belting is due to the high convexity with which most pulleys are made. A convexity of $\frac{1}{16}$ inch is sufficient for pulleys 6 inches wide and under; the smaller or driven pulley may be made perfectly flat. The Author discusses belt- *versus* rope-driving, and expressed his opinion strongly in favour of belts.

A. S.

Standardizing of Generators, Motors and Transformers.

(American Institution of Electrical Engineers, vol. xv., 1898, pp. 71–100.)

This is a discussion at the American Institution of Electrical Engineers on the advisability of having all dynamos, transformers,

etc., of standard sizes, so as to render pattern-making less laborious, and the manufacture of the machines cheaper. The question was referred to a select committee.

W. G. R.

Single-phase Induction Motor. C. P. Steinmetz.

(American Institution of Electrical Engineers, vol. xv., 1898, pp. 103–183.)

When running at or very near synchronism, the magnetic field of the single-phase induction motor is identical with that of the polyphase motor, since in a turn wound at right angles to the primary winding at synchronism an electromotive force is induced equal to that induced in a turn of the primary winding, but differing therefrom by 90° in phase.

The greater portion of this Paper is devoted to starting devices. All starting devices of the commutatorless single-phase induction motor consist in the production of a component of magnetic flux displaced from the axis of polarization of the induced currents, and may be grouped into three classes, viz.:—

1st. *Phase splitting Devices*, in which the primary system is composed of two or more circuits displaced from each other in position, and combined with impedances of different inductance-factors so as to produce a phase-displacement between them.

2nd. *Induction Devices*, in which the motor is excited by a combination of two or more circuits which are in inductive relation to each other. This mutual induction between the motor circuits can either take place outside the motor in a separate phase-splitting device, or in the motor proper.

3rd. *Monocyclic Starting Device.*—An essentially wattless electromotive force of displaced phase is produced outside of the motor, and used to energise a cross-magnetic circuit of the motor, either directly by a special tease-coil on the motor, or indirectly by combining this wattless electromotive force with the main electromotive force, and thereby driving a system of electromotive forces of approximately three-phase or any other relation.

Each of these types of starting devices is discussed in detail, the object being to inquire into the starting torques and the acceleration produced. The Author concludes that of all single-phase induction-motor starting devices, the monocyclic device most nearly reproduces in starting and accelerating the conditions of the polyphase motor. In the discussion which followed the reading of the Paper, the question of the legitimacy of the assumption of sine currents and electromotive forces arose. The general opinion was that the results obtained on that assumption agreed so nearly with actual practice as to justify its use.

W. G. R.

Asynchronous Motors. E. J. Brunswick.

(Électricien, vol. xv., 1898, pp. 305–307, 321–324 and 340–344.)

The condition that the torque in a polyphase motor should be independent of the speed of the rotor is

$$R = pL;$$

where R is the resistance and L the coefficient of self-induction of each rotor circuit, and p is 2π times the frequency of the induced currents. From this it follows that a uniform torque could be obtained as the rotor runs up to speed by having variable resistances in the rotor circuits, and gradually cutting them out as the speed increases. Such a process involves rubbing contacts and probability of sparking, both of which are undesirable. In the Boucherot system the same end is attained by different means. The stator, instead of being wound in the ordinary fashion, consists of two distinct windings, one of which is fixed, and the other is capable of rotating through an angle representing half a period of the supply current. Thus in a four-pole motor the possible angular rotation is 90°. The movable part of the stator assumes the displaced position at start, and is rotated back again on full speed being attained. The rotor is of special design, but still consists of short-circuited bars without any rubbing contacts whatever. Three types of motors are constructed according as the motor is to be placed in an accessible place or not, or in the case where the conditions require a minimum number of conductors.

W. G. R.

Thickness of Transformer Plates. W. Dittenberger.

(L'Éclairage Électrique, vol. xv., 1898, p. 362.)

Loppé has recently[1] given the following formula for the loss per cubic centimetre of iron in the core of a transformer :—

$$W = \alpha \frac{B'^{1 \cdot 6} (e + \epsilon)^{1 \cdot 6}}{e^{1 \cdot 6}} + \beta B'^2 (e + \epsilon)^2,$$

where e is thickness of plates, ϵ that of insulation between them, B' = magnetic flux per square centimetre of section of core, and α and β are constants. Using this expression, Loppé graphically determines the value of e, which will render B' a maximum for given values of W and ϵ. The Author solves this problem

[1] L'Éclairage Électrique, vol. xi., 1897, p. 548.

analytically, and finds that the required value of e is given by the equation—

$$W = a \cdot \frac{\epsilon_4}{e^{12}} \left(\frac{4\,a}{4\,\beta}\right)^4 \cdot \left(1 + \frac{4}{5}\frac{\epsilon}{e}\right),$$

an approximate solution of which may be easily obtained.

A. H.

Plant of the Ellicott-Square Building, Buffalo, N.Y.

F. L. Wilson.

(Electrical World, vol. xxxi., 1898, pp. 519–522.)

A feature of interest in the electric plant of the Ellicott Building is the system of regulation of the forced draught. The system, due to Mr. John Beckman, depends upon the action of three valves. A regulating valve is placed on the inlet-pipe to the engine which drives the blower. This valve is so arranged as to open and increase the speed of the blower engine as the pressure of the steam in the boiler falls below the desired point, and to close and decrease the speed as the pressure rises. A pressure-reducing valve is placed in series with the regulating valve to limit the speed of the fan, and to set the draught pressure in such a manner as to produce the most efficient combustion, and create under the boiler the greatest heat that the water is capable of absorbing. The stack damper is set to hold back this heat, so that the escaping gases do not leave the uptake at more than 100° above the temperature of the steam. When the steam pressure in the boiler has reached the desired point, the regulating-valve cuts off the direct supply of steam to the blower-engine, and the fan would stop but for the introduction of a by-pass consisting of a small pipe supplied with a reducing-valve. By this means steam just sufficient to keep the fan revolving, and at a low pressure of 6 or 8 lbs., is supplied to the engine. The following results of tests on the working of the plant are worthy of notice :—

Water evaporated per lb. of coal	6·77
Equivalent from and at 212°	8·18
Equivalent water per lb. of combustible from and at 212°	9·03
Commercial HP. of boilers, based on 30 lbs.	250·00
Builder's rating	250·00
Average amount of steam supplied to electric-light engine per electric HP.-hour (lbs.)	36·73
Average output for 8,760 hours (365 days), kilowatts .	77·99
Heaviest load, kilowatts	260·00
Average coal per ampere-hour, lbs. (water supplied at 56°)	0·84
,, ,, ,, ,, (water supplied at 183°) .	0·75

W. G. R.

High-Voltage Transmission Lines. S. H. Dailey.

(American Electrician, vol. x., 1898, pp. 194–197.)

This is an article on the practical details to be noted in the erection of a high-voltage transmission line. Special attention is paid to safety devices, and the Author recommends that a barb wire should run the entire length of the line, and grounded every half-mile.

W. G. R.

Protection of Three-Wire System. E. Oxley.

(Electrical Engineer, New York, vol. xxv., 1898, pp. 483–484.)

The Author refers to the trouble which may be caused to that side of a three-wire system which has the smaller load due to a sudden and considerable increase in the potential reproduced upon that side, such increase being produced by opening the neutral, or balancing wire, by the blowing of its fuse. The increase in potential from this cause may reach a point where it is almost double the voltage that should normally exist. The injury to incandescent lamps, fan-motors, and enclosed arc-lamps may be considerable. The "over-fusing" of the neutral wire, which has come to be a common practice among wiremen and others, came into existence, and owes its prevalence to the fact that it has hitherto been the only known expedient for avoiding disturbances of this character. This practice of "over-fusing" the neutral wire is directly contrary to the rules of the Board of Fire Underwriters. The Author points out that there is a far greater menace to property, however, in the fact that the abnormal tension on the underloaded side of the system, upon the blowing of the neutral fuse, develops weak spots in the wiring; or if such places already exist, the insulation quickly gives way under the strain, and destructive fires may be the direct result. To remove the possibility of such disturbances occurring, the Author has devised a simple safety attachment for a three-pole switch, of which illustrations are given. The principle of its operation consists in automatically opening the switch by the action of a spring immediately upon the blowing of the neutral fuse, the switch being maintained in its closed position by a latch or catch. This latch is released, or withdrawn from its locking engagement, by the attraction of a small electromagnet having its terminals connected to the ends of the neutral fuse. So long as the fuse remains intact no current flows through the windings of the magnet, as the potential at its terminals is only that due to the drop in voltage in the neutral fuse itself. Upon the blowing of the fuse, however, the potential between the points of connection immediately rises, causing current to flow through the magnet

coils, thus energizing the magnet sufficiently to enable it to release the catch. Although the winding of the magnet is in parallel with the neutral fuse, it does not in any degree affect the carrying capacity of the latter, as the resistance of the coils is great relatively to that of the fuse. The opening of the switch follows so closely upon the blowing of the fuse that it is said to be practically impossible to distinguish the interval which separates the two occurrences.

L. J. S.

Long-distance Transmission Experiment at Ogden.

(Electrical Review, New York, vol. xxxii., 1898, p. 287.)

This experiment was carried out at Ogden, Utah, in order to ascertain the limits within which high-voltage currents may be used commercially. The experiment was made by F. O. Blackwell over the lines which connect the power station at Ogden with the distributing circuits at Salt Lake City, the complete transmission circuit being 73 miles long over three No. 1 wires. The amount of power transmitted amounted to 1,000 HP., and the transmission voltage at times reached 30,000 volts. The current on the return was delivered to resistance-vats at the power-house, consisting of three wooden tanks. This power was transmitted with a loss of only 9 per cent., including 4 per cent. loss in the two sets of transformers. Continuing the experiment, part of the Salt Lake City station load was run from Ogden with current at 24,000 volts. This was supplied to about 500 HP. in synchronous motors and lights for two days under severe climatic conditions without the slightest hitch.

W. G. R.

St. Anthony Falls Water-Power Plant.

(American Electrician, vol. x., 1898, pp. 185–192.)

These works were recently constructed by the St. Anthony Falls Water Power Company, and on completion were leased to the Twin City Rapid Transit Company, to furnish power for street railways in Minneapolis and St. Paul, supplanting the steam-driven machines at first installed. The site of the generating works is in Minneapolis, just below the St. Anthony Falls on the Mississippi. A V-shaped dam, with a crest about 1,000 feet long, has been constructed of cut granite, and gives a maximum head of 22 feet; it is provided with sluices, waste weirs, etc., of which a full description is given. The power-house, which forms part of the dam, contains room for ten 700 kilowatt sets, seven of which are now installed, and two smaller sets for supplying exciting current. The main turbines consist of two pairs of 42-inch

horizontal water-wheels on the same shaft directly connected to a generator; the sluices for each set are regulated by a governor driven by belting off the generator shaft. In the generating station there are already installed five three-phase alternators yielding 700 kilowatts at 3,450 volts with frequency about 35; two 700-kilowatt direct-current dynamos feeding a 500-volt railway circuit direct; and two 100-kilowatt 6-pole exciters. There are three substations: to No. 1, about 1¾ mile distant, current is transmitted at 3,450 volts and actuates two 600-kilowatt rotary converters; these are of the 8-pole type, giving 580 volts on the direct-current side at 530 revolutions per minute. No. 2, situated about 4½ miles from the main station, contains one rotary converter of the same type supplied at the same voltage. No. 3, ten miles distant, is supplied at 12,000 volts, and contains two similar converters. Twenty-one 233-kilowatt transformers are installed, six at the main station and fifteen in the substations. The transmission is by paper-insulated lead-armoured triple conductors laid underground, two leading to substation No. 1, and one each to the other substations. The Paper is illustrated by eighteen views of different parts of the plant.

M. G. W.

Booster System in Electric Railways. J. L. Woodbridge.

(Journal of the Franklin Institute, vol. cxlv., 1898, pp. 374–385.)

Booster is any electro-magnetic generator whose armature is connected in series with a feeder with the object of compensating for drop of voltage in that conductor due to the current which it is transmitting. In lighting and traction work it has proved very useful, rendering it possible to take up loss in feeders too long to form part of the main system. In every case of heavy drop in feeders, boosting involves difficulties in keeping uniform voltage along the whole line. It is practically equivalent to a very strong over-compounding, reinforcing the system only in the needy branches. Any spare generator in the station can be used for the purpose. A "compound series booster" is simply an ordinary compound-wound constant potential machine, connected by a double-throw switch, to serve (1) as a booster when required, or (2) as an ordinary generator. The shunt-coils are connected in parallel with each other and with a certain portion of the feeder, so that a small but constant percentage of current circulates through them, and, like the series coils, the magnetizing force is proportional to the load, obtaining thus the series effect from both shunt and series windings. The variation of voltage is carefully gone into, and its causes inherent in the booster machine. (1) Saturation of field-magnets. When using a machine on hand with this fault, remedy it by limiting the load, or providing

sufficient copper in the feeder to limit the maximum voltage required and range of magnetization. (2) Hysteresis effects have little importance in railway work owing to the peculiar nature of the variations of load. (3) Sluggishness, due to inductance and Foucault currents. The effect of high inductance of shunt-fields is rather more serious, and this is minimized by limiting the extent of their magnetizing force by dividing them up in parallel, thus tending to check the portion which will lag. As a rule it is not advisable to operate the booster continually, but to put enough copper to carry ordinary loads satisfactorily, reserving the booster for times of excessive traffic. But with a low price of fuel it pays to use a booster for as much as 18 hours a day. The booster system, if used with skilled judgment, may save a large expenditure in copper at the cost of an amount of wasted energy that is well within the limits of economy.

P. D.

Accumulator Traction.

(Electrician, vol. xli., 1898, pp. 9, 10.)

An abstract is given of a report drawn up by a deputation of the Blackpool Corporation after visiting various Continental systems of electric traction. The estimated cost is given of supplanting the present conduit system by accumulator traction. The rolling-stock consists partly of double-bogie cars weighing 11 tons and partly of smaller cars weighing 7½ tons. The relative costs of maintenance work out to the following figures:—

	£
Overhead system	600
Conduit system, cost during 1897	2,238
Accumulator system	2,799

W. R. C.

Accumulator Road Traction. J. T. NIBLETT.

(Mechanical Engineer, vol. i., 1898, pp. 520–531, 566–568, 607–609, 628–629.)

A variety of forms of storage-cells—both obsolete and in present use—are described, and some elementary data given concerning the calculation of internal resistance, efficiency, and so forth. Many particulars as to the construction and working of the electric cabs now running in London and in New York are also given. The former carry forty Faure-King cells having a total weight of 14 cwt. and an output of 170 ampere-hours when discharging at a 30-ampere rate. One motor of the Johnson-Lundell type is used, capable of normally developing 3 HP., and provided with

double windings on both fields and armature for the purpose of obtaining the various speeds. The latter contain forty-four three-plate cells of the chloride type, whose total weight is 900 lbs. and capacity 100 ampere-hours at a 21-ampere rate. Two motors, each of 1·5 HP. at 800 revolutions, are employed.

E. J. W.

Electric Traction. G. Pellissier.

(L'Éclairage Électrique, vol. xiv., 1898, pp. 449–456; vol. xv. pp. 63–67, 140–143, 187–189.)

The Author gives an account of various patents relating to electric traction. Among the number are included the Blackburne and Spence system of traction, the Priest and Merrick pneumatic series-parallel controller, the MacElroy truck, the arc-trolley of the Industrie Électrique Company, and that of Siemens. Some account is given of the New York conduit-lines. The Author then describes the conduit systems of Griffin and Small, Hecker, Allen, Nigel, Harington, Balfour, and Smith, in which a small trolley within the conduit is magnetically attracted by the car and thus caused to run with it, making alive the various sections of a rail on the surface; of Siemens, and of Arno and Caramagna.

W. R. C.

Counterweight System in Electric Cable Tramways.

(Street Railway Review, vol. viii., 1898, pp. 286–288.)

The grade of the tramway begins at 5 per cent., increasing gradually to 16 per cent., then falling to 4 per cent. The vertical height attained is more than 100 feet. In going up- or down-hill, each passenger-car is controlled by a grip-car immediately below it on the grade; the grip-car is attached by a gripping device to the cable, and a counterweight running in a tunnel half the length of the tramway balances the weight of the cars. There are thus no counterweight cable fastenings and draw-bar connections. A number of drawings are given illustrating the mechanical construction of the line.

A. S.

Electric Street-Railways in Baltimore. C. B. Fairchild.

(Electrical Engineer, New York, vol. xxv., 1898, pp. 569–571.)

This is a description of the Baltimore City Passenger Railway, which is about to be transformed into an electric line. Formerly the cable cars were operated in trains, consisting of an open grip-car and trailer. The train system still remains; but the open grip-cars have been converted into trailers, and the closed cars used for the grip-car.

W. G. R.

Best Arrangement of Return Feeders for Traction.

F. Natalis.

(Street Railway Journal, vol. xiv., 1898, pp. 277-283.)

To tramway engineers the arrangement of the return feeders is an important question. The rails alone are seldom of sufficient carrying capacity for returning the current to the power-station. Large potential differences between two points on the line are not admissible, on account of so-called "vagabond currents," which disturb telephones and scientific instruments, ruin pipes, etc. The local authorities usually insist upon a definite maximum fall of potential on the return circuit. Return feeders are at best expensive; and if their number and locations are unwisely chosen, their cost of construction is considerably increased. The Author gives a number of formulas and examples for settling this important question, and concludes this article by stating that, considering what great expenses are often involved, it is well worth the trouble to make use of such formulas. In these calculations, as well as in many similar ones, many things must of course be left to the judgment of the engineer.

L. J. S.

Rail-Bonding. J. R. Chapman.

(Street Railway Review, vol. viii., 1898, p. 347.)

A cast-welded joint in a 56-lb. rail, which had been in use for 2½ years and was worn out, was tested, with the results tabulated below, showing that the conductivity of the joint was practically equal to that of the rail. The joint was afterwards sawn through; a view of the section is given.

Test No.	Average Amperes Flowing.	Drop in 5 feet with Joint.	Drop in 5 feet without Joint.	Drop in Volts per 100 Amperes Flowing.
		Volts.	Volts.	
1	502·6	..	0·047	0·00935
2	508·9	0·048	..	0·00943
3	735·8	0·065	..	0·00883
4	758·8	..	0·069	0·00910

Temperature of rail during tests, 80° F.

A. H. A.

Theory of Deformation of Metals. Brillouin.

(Annales de Chimie et de Physique, vol. xiii., 1898, pp. 377–404.)

As a result of microscopical examination and metallurgical investigation, the ordinary metals used in construction are assumed in this memoir to be composed of a great number of very small crystalline elements or grains embedded in a network of viscous matter. The crystalline elements are supposed to be possessed of elasticity but to be deprived of viscosity, whilst the surrounding network is deprived of elasticity. The Author then proceeds to show how the laws of permanent deformation follow from this assumption. The present memoir deals with homogeneous deformation. Hook's law is assumed for the elasticity of the crystals, whilst the linear law expresses the viscosity. The deformations due to the crystalline and viscous components of the metal are then calculated, the former being simply the ordinary elastic deformations, and the latter being obtained by integrating the ordinary equations for a viscous fluid for the form of the network in question. The total deformation is thus shown to consist of a term representing the elastic deformation of the crystalline elements, and a term consisting of some function of $\int_0^t X\,dt$ (X being the deforming force, and t the time), which represents the viscous deformation. The Author lays great stress upon the importance of taking account of the time in making experimental tests, especially where stops are made with the specimen under load, and states that many of the irregularities in the results obtained in mechanical laboratories, which have usually been put down to faults in the metal, may probably be accounted for by neglect of this precaution.

The equation obtained for the deformation is then put into the following form—

$$x = \mathrm{K}\,\mathrm{X} + \phi\left(\int_0^t \mathrm{X}\,dt + \mathrm{A}\right) - \phi\,\mathrm{A},$$

X being the force and x the length, and A being a constant

depending on the initial state of hardness of the metal. For a rapid variation of load without shock, the deformation is shown to be elastic, and the coefficient of elasticity is defined as being fixed by the amount of the sudden variation of the deformation when produced without shock. Thus, to obtain the coefficient of elasticity, it is necessary to measure the initial value of the alteration of the deformation. It is then shown that, after a stop of great length under the action of a load, a small deformation effected rapidly without shock is purely elastic. Considering the case of deformation produced at a constant rate, the Author shows that the resulting relations agree with the law discovered by M. Bouasse in his experiments upon the torsion of a platinum wire (Comptes Rendus, Feb. 1897). After discussing the case of a cycle performed at a constant rate, interrupted by stops under load, the Author gives some geometrical illustrations of the foregoing, and concludes by indicating the treatment of torsion and bending, and also the influence of temperature and physical properties of the metals on the function ϕ.

A. Gs.

Solar Radiation in the High Alps. G. B. Rizzo.

(Nuovo Cimento, 1898, pp. 120–130.)

The formulas of Pouillet ($Q = Ap^{\epsilon}$), Crova $\left(Q = \dfrac{A}{(1+\epsilon)^{n}}\right)$, and Bartoli ($Q\,\epsilon^{n} = K$), for the quantity of solar heat incident per unit of normal area, though Crova's works best, are all subject to the objection that, when the sun is in the zenith ($\epsilon = 0$), the values obtained for the solar constant become inadmissible, as they also do with Ångström's binomial formula—

$$Q = (2{\cdot}568 \times 0{\cdot}751^{\epsilon}) + (10{\cdot}335 \times 0{\cdot}049^{\epsilon}).$$

Observations made on the Rocciamelone in the Val de Susa, at different heights, gave on reduction the formula $Q_1 = a - b\mu^{n}$ for the value of the solar radiation considered as zenithal, μ being the mass of air already traversed by that radiation; and the solar constant has a value very near 2·5 small calories per minute and per square centimetre, this value being, of course, apart from that of any particular radiations to which the upper regions of the atmosphere may be opaque.

A. D.

Properties of Nickel-Steels. C. E. GUILLAUME.

(Journal de Physique, vol. vii., 1898, pp. 262–274; also Comptes Rendus, vol. cxxvi., 1898, pp. 738–740.)

The characteristics of various compounds of iron and nickel are considered. With regard to magnetic properties, nickel-steels containing besides iron and nickel only small quantities of carbon, silicon, and manganese, fall into two distinct categories. The first, containing from 0 per cent. to about 25 per cent. of nickel, and which seem comprised pretty accurately between the formulas Fe and Fe_3Ni, are "irreversible," in the sense that at one and the same temperature they can exist in two essentially different states, according to the preceding cycle of temperatures. When these alloys are heated they lose their magnetism gradually between two temperatures, which are comprised for all the alloys between dull red and cherry red. When they are cooled they pass again through the same temperatures without becoming magnetic, and only re-acquire their first condition at a temperature lower than those between which the loss of magnetism occurs. The return to the magnetic state takes place for an alloy with 24 per cent. nickel a little below zero. The presence of chromium lowers the temperature at which the return takes place. The steel, with 22 per cent. of nickel and 3 per cent. of chromium, remains non-magnetic even in liquid air. Steels with more than 25 per cent. of nickel are "reversible," and possess, at each temperature, magnetic properties which to a first approximation depend only on the actual temperature. The expansion of the material has been observed by comparison with a brass scale. The phenomenon noticed by A. Le Chatelier has been confirmed; the expansion for the same alloy is much more feeble in the magnetic state than in the non-magnetic state. The transformation is gradual as regards expansion as well as regards magnetism, and the same alloy may possess any coefficient of expansion between two determined limits according to its degree of transformation. In one of the extreme states the expansion is a little greater than that of brass; in the other it is lower than that of ordinary steels. At ordinary temperatures the steels of the second category possess a coefficient of expansion which varies continuously with the composition. Steels containing 35 per cent. to 36 per cent. of nickel expand ten times less than platinum. Other mechanical constants and their changes are also referred to. The alloys of the first group in passing from their non-magnetic state, where they are relatively soft and easily deformed, to the magnetic state, when they become hard and very elastic, undergo a diminution of the modulus of elasticity. The nickel-steels possess a high specific resistance, and the transformations which they undergo do not seem to affect the variations of the electric resistance; the curve of change is an ordinary one. The variation of resistance with temperature seems to be independent of the variations of

volume. For the alloys of the first sort the passage to the magnetic state takes place with increase of volume. A chemical origin is suggested for the peculiarities of behaviour, and it is supposed that definite chemical compounds tend to be formed. The experiments show that the irreversible nickel-steels can possess between extended limits of temperature an indefinite number of states of equilibrium, which they keep almost without modification so long as the alloy does not cut, at low or high temperatures, two curves of transformation along which all its properties change gradually and simultaneously. They possess, besides, unstable states of equilibrium which can be broken quickly, and to which an almost instantaneous transformation puts an end. See also Phys. Soc. Abstracts, Nos. 469 and 517, 1897.

J. J. S.

Deformations of Dielectric in Electric Field. P. SACERDOTE.

Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxvi., 1898, pp. 1019–1022.)

The unitary deformations undergone by a plate of dielectric substance are always proportional, if the temperature be kept constant, to the electric energy per unit of volume, $\frac{K H^2}{8 \pi}$. The coefficients are $(k_1 + a)$ for the unit deformation perpendicular to the field, $(k_2 - a - 2b)$ for that parallel to the field, and $\left(k + \frac{c}{3}\right)$ for the variation of volume per unit of volume; a and b being the coefficients of longitudinal expansion and transverse contraction, and c that of cubical compressibility, k_1 the coefficient of variation of K, with traction perpendicular to the lines of force, k_2 that with traction parallel to them, and k that with uniform superficial traction. These k's are all small; if negligible, the result is that there is always contraction in the direction of the lines of force, lengthening transversely, and an increase of volume.

A. D.

Photo-electric Relations of Coloured Salts.

J. ELSTER and H. GEITEL.

(Annal. Phys. Chem., vol. lxii., 1897, pp. 599–602.)

Just as chloride of sodium and other salts which have become coloured through exposure to kathode rays have their colour discharged by exposure to sunlight or daylight, so do these salts when they have acquired similar colours through exposure to

potassium or sodium vapour. When coloured with a trace of Prussian blue they do not. Everything points towards these coloured products being solutions of traces of the metal in the solid salts.

A. D.

Relations between Luminous and Chemical Energy.

BERTHELOT.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxvii., 1898, pp. 143–160; see also Comptes Rendus, vol. cxxvii. p. 84.)

This series of experiments were conducted at the ordinary temperature under (1) direct sunlight, (2) diffused daylight, (3) darkness; also with interposition of various liquids and solutions, with a duration of weeks or months. Nitric acid and nitric anhydride, when pure, underwent no decomposition in the dark. But the former, under protracted exposure to solar light, gave amounts of oxygen corresponding to from 12 to 42 per cent. of the total transformation $2HNO_3 = 2NO_2 + O + H_2O$, free nitrogen and nitrous oxide being absent. The effects of light are parallel to those of heat, but produced at a lower temperature. Diluted nitric acid (1·365 specific gravity) was found to be practically stable in solar light, probably because the layers of NO_2 which might be formed tended to absorb the actinic rays. A solution of potassium dichromate completely arrested the effective solar radiation, whereas ammonio-sulphate of copper in fairly thick layers did not.

Numerous trials were made with chloride of silver, hydriodic acid, and other bodies affected by light, which showed that the changes, as in the case of heat, were reversible under exothermic or endothermic conditions. Copious details of the experiments are given in the original Paper.

S. R.

Sayers' Automatic Third-Brush Regulation of Dynamos.

(Electrician, vol. xli., 1898, pp. 358–359.)

If a third brush is arranged to bear on the commutator of a dynamo at a position midway between the ordinary brushes, the voltage between this brush and either of the other brushes will be the same when the machine is running light. When load is put on the field becomes distorted, and the voltage between the backward main brush and the third brush is reduced, while the voltage between the forward main brush and the third brush is increased. If the shunt-coils are wound to give the light-load ampere turns required with half the voltage of the machine,

automatic regulation may be obtained by connecting the shunt-coils to the third brush and the forward main brush. Table I

TABLE I.

Revolutions.	Volts at Brushes.	Amperes.	Revolutions.	Volts at Brushes.	Amperes.
698	115·0	58	702	115·0	138
692	114·0	90	686	114·5	155
694	115·0	90	700	114·0	180
698	115·0	110	720	115·0	250
700	115·2	110	730	115·0	250
695	115·0	100	..	..	..

gives results of a test of a 120-volt 300-ampere machine with the shunt coupled in the ordinary way. Table II. gives results of

TABLE II.

Revolutions.	Volts at Main Brushes.	Volts on Shunt.	Amperes.	Revolutions.	Volts at Main Brushes.	Volts on Shunt.	Amperes.
676	114·0	63·0	0	652	115·0	72·3	174
651	114·5	65·3	50	644	115·0	71·8	171
650	114·5	68·2	90	652	115·0	74·6	234
644	114·0	69·8	139	653	115·0	77·2	280

a test with the shunt coupled in parallel, and one end coupled to the third brush as described; this Table shows a rise of pressure on the shunt between no load and full load of 22 per cent.

The arrangement of the third brush can easily be applied to any existing machine having more than one shunt-coil in series, the coils being connected in parallel so as to adapt them for excitation with half the machine voltage.

W. G. R.

Electric Traction on Railways. P. LANINO.

(Elettricità, Milan, vol. xvii., 1898, pp. 164–165 and 183–185.)

Improvements in train service take the form of greater speed and more commodious carriages, the latter necessitating greater weight. Both of these require a more powerful locomotive; but, as the permanent way limits the size and weight of the locomotive, improvement ultimately consists in reduction of weight of the motor per HP.

The Author considers that for steam-locomotives the limit has now been reached, the best types developing 1,800 HP., and

weighing 154 lbs. per HP. For progress, therefore, he looks to the electric motor fed from a central station, this being the lightest motor known; he believes that the weight can be reduced to 22 lbs. per HP., and that the absence of any reciprocating parts removes all limit to the ultimate speed attainable.

He describes the scheme of Davis and Williamson for an electric railway between New York and Philadelphia, to run at a speed of 187 miles per hour, and of Behr for a permanent way consisting of five rails supported on inverted V trestles. The latter, when tried at the Brussels Exhibition of last year, failed on account of the instability of the trestles.

Criticising the Heilmann locomotive, the Author expresses his opinion that this will never prove superior to the ordinary steam one, as the great disadvantage of extra weight (220 lbs. per HP.) will outweigh the advantages of independent driving of each axle, triple expansion engines and greater regularity in the working of the engines. He believes that the present field of electric traction is that of local lines requiring frequent journeys and light trains, and cites as a successful example a three-mile trolley line opened at Baltimore in 1895. The locomotives weigh 90 tons, and have motors of a total power of 1,600 HP. distributed on six independent driving axles. The works cost per ton-mile, when one, two, or three locomotives are running, are, respectively, 0·186, 0·123 and 0·1015 penny.

G. H. BA.

Efficiency of Glow-Lamps. J. E. RANDALL.

(Mechanical Engineer, vol. i., 1898, pp. 636–638.)

The Author briefly reviews the various advances made in lamp manufacture within recent years, and in illustration of the superiority of the modern cellulose filament over the older bamboo one gives the following Table:—

Duration of Run, in Hours		0	100	200	300	400	500	600	700
Average candle-power	110-volt cellulose	16	15·8	15·86	15·68	15·41	15·17	14·96	14·74
	110-volt untreated bamboo	16	14·1	12·9	11·8	11·0	10·4	9·9	9·6
	50-volt treated bamboo	16	15·8	15·3	15 0	14·6	14·2	14·0	13·7
Average watts per candle	110-volt cellulose	3·16	3·26	3·13	3·37	3·53	3·51	3·54	3·74
	110-volt untreated bamboo	3·20	3·50	3·80	4·08	4·32	4·53	4·75	4·90
	50-volt treated bamboo	3·20	3·28	3·37	3·45	3·53	3·61	3·67	3·76

A. H.

Oxygen in Helium Stars. F. McClean, M. Inst. C.E.

(Proceedings of the Royal Society, vol. lxii., 1898, pp. 417–423.)

The Author has recently returned from the Cape, where he has obtained the spectra of 116 stars with the aid of his large objective prism attached to the Astrographic Chart telescope at the Observatory there. In his discussion of the spectra he finds in many of the stars what he calls "extra" lines, outstanding from the usual helium and hydrogen lines; and to show the probability of these being due to oxygen, he maps the spectrum of oxygen alongside the stella spectra. The evidence afforded by the many apparent coincidences seems to him to be sufficient to warrant their being accepted as oxygen lines.

C. P. B.

Celestial Phenomena and Kathode Rays. H. Deslandres.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxvi., 1898, pp. 1323–1326.)

The Author, profiting by his observations of the total eclipse of the sun in 1893 to investigate the chromosphere and corona, traces a connection between these phenomena and the appearances exhibited by various combinations of kathode rays. His special experiments with kathode rays have been described in a former Paper (Comptes Rendus, vol. cxxiv., pp. 678, 945, 1,297, and vol. cxxv., p. 373). The two points to which he draws special attention are: (1) the attraction exerted by an anode on a kathode ray; (2) the non-repulsion by a kathode when a solid body is interposed in the path. In the eclipse of 1893, the Author says he found certain regions of the solar surroundings to emit kathode rays. He regards the base of the solar atmosphere as being the seat of this emission, the rays being most intense where the chromosphere is brightest, viz., above the spots and faculæ. By considering the combined result of the solar attraction and the kathode ray repulsion on particles of matter surrounding the sun, he explains the production of the corona and comets. He regards the light of these objects to be produced by the heat and phosphorescence induced by the impact of the kathode rays upon the matter surrounding the sun. The fact of the tails of comets being always turned from the sun is also explained. The particles of matter are assumed very small. Then the attraction being proportional to the mass, and the kathode repulsion proportional to the surface, the latter may eventually overcome the former; hence the outward direction of the cometory appendages. Perrin is cited as authority for stating that the kathode ray carries a negative charge, which will modify the electric and magnetic state of the sun, thereby producing such phenomena as auroræ and terrestrial

magnetic storms. In conclusion, the Author points to a possible proof of his view. The varying periods of brightness of comets should correspond to the passage of some large sun-spot or facula near the line joining the comet to the sun's centre.

C. P. B.

Electrodynamic Slit Action. M. Latrille.

(Annalen der Physik und Chemie, vol. lxv., 1898, pp. 408–430.)

A narrow slit transmits polarized light to a different extent according to the angle between the slit and the plane of polarization of the light. In electro-magnetic waves a similar observation is made. The greatest transmission is obtained when the slit is perpendicular to the direction of the vector of electric force. The Author investigates the dependence of the transmitted energy upon the width of the slit. The indicator used is a coheror, and it is found that the direction of the axis of the latter also influences the result, since it reacts more strongly upon electric vibrations along its axis than across it. When the slit is increased in length, the energy transmitted increases rapidly at first, and then more slowly. When the width is increased, the energy transmitted increases slowly at first, and then at a greater rate up to a certain maximum. The absorption is due to the resonance of the edges of the slit.

E. E. F.

Ketteler-Helmholtz Dispersion-Formulas. A. Pflüger.

(Annalen der Physik und Chemie, vol. lxv., 1898, pp. 173–213, and pp. 225–228.)

The formulas are

$$n^2 - \kappa^2 - 1 = \Sigma \frac{D\lambda^2 (\lambda^2 - \lambda^2_m)}{(\lambda^2 - \lambda^2_m)^2 + g^2\lambda^2} \quad . \quad . \quad . \quad (1)$$

$$2n\kappa = \Sigma \frac{Dg\lambda^3}{(\lambda^2 - \lambda^2_m)^2 + g^2\lambda^2} \quad . \quad . \quad . \quad (2)$$

To test them experimentally, let corresponding values of λ, n, κ, be observed; then, by a tentative process, a set of values (λ_m, g) are found, so that the graphs for

$$\left.\begin{aligned} y &= \frac{2n\kappa}{\lambda^3} \\ \text{and} \qquad y &= \Sigma \frac{Dg}{(\lambda^2 - \lambda^2_m)^2 + g^2\lambda^2} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (3)$$

agree. Now (1) may be written in the approximate form

$$\left(n^2 - \kappa^2 - a - \frac{b}{\lambda^2} + c\lambda^2\right)\frac{1}{\lambda^2} = \Sigma \frac{D(\lambda^2 - \lambda^2_m)}{(\lambda^2 - \lambda^2_m)^2 + g^2\lambda^2} \quad (4)$$

where a, b, c are constants, and the values of (λ_m, g) on the right hand are the same as those calculated from (3). Three separate determinations of n, κ fix the constants a, b, c; and if, for these values, the equation (4) is approximately satisfied for a wide range of λ, this is, so far, a confirmation of the original formulas (1) and (2).

The object of this research is to test the theory by observations upon solid substances showing anomalous dispersion, and for this purpose cyanin and fuchsin were selected. To determine κ, the index of absorption, thin films of the pigment were deposited on glass plates, and their thickness found by Wernicke's modification of Weiner's method; κ was then deduced from observations with König's spectral photometer. The values of n (the index of refraction) for fuchsin in the ultra-violet were found by a method suggested by Kayser. An iron spectrum of wide dispersion was obtained by means of a narrow slit and a Rowland concave grating of 6·5 metres focal length. The rays of a portion of this fell upon a double prism of fuchsin deposited on a quartz plate, and after this upon a photographic plate, where two images of each spectral line were produced. Let d' be the distance between them; then, if the double prism is sufficiently far from the photographic plate,

$$n = \frac{\left(\beta + \frac{d'}{\delta}\right)}{\beta},$$

where β is the sum of the very small angles of the prism in seconds, and δ is the (calculated) value of d' for an angular deviation of one second. The values of n for cyanin in the visible part of the spectrum were also carefully determined directly by means of a spectrometer: the results are tabulated and compared with the Author's previous results.

The final conclusion is that, so far as the visible spectrum is concerned, the Ketteler-Helmholtz dispersion formulas applied to media whose optical constants are exceedingly variable within a very small range of wave-length, are (allowing for unavoidable experimental errors) so far consistent with observation that they account for the greater part of the two graphs

$$y = \frac{2n\kappa}{\lambda^3}, \quad y = \left(n^2 - \kappa^2 - a - \frac{b}{\lambda^2} + c\lambda^2\right)\frac{1}{\lambda^2},$$

which are deduced from experiment. There is, however, a discrepancy for the re[illegible] he spectrum.

In the suppleme[illegible] is remarked that the optical

constants of cyanin, deduced indirectly by means of Cauchy's formulas for metallic reflection, agree very well with the values observed directly, except for the red part of the spectrum. For this the values of n agree with those observed, but the values of κ come out larger. If these larger values of κ are used, the discrepancy above alluded to disappears.

G. B. M.

Kathode and Röntgen Radiations. A. A. C. Swinton.

(Royal Institution Discourse, 4 February, 1898; Electrician, vol. xli., 1898, pp. 246–248, and pp. 317–319.)

A pear-shaped Crookes' tube is suspended over a straight electro-magnet, towards one pole of which the kathode beam is projected. When the magnet is excited, the beam is drawn down to a fine point, which rapidly erodes the internal glass surface of the tube. By moving the tube or the magnet, any desired pattern can be engraved on the glass. In another experiment two concave kathodes are arranged to focus on a small piece of quicklime, placed between them. The kathodes are supplied with alternating current, at about 20,000 volts, and a very brilliant and beautiful light is produced by the incandescence of the quicklime. The light is found to fluctuate in a curious manner, and after a short time the kathode rays bore perfectly straight and very minute holes, right through the lime. It may eventually be found possible to produce commercial high-voltage lamps on this principle of much higher efficiency than filament lamps, and possibly even rivalling arc lamps. The luminous material in this case need not be a conductor, and there is therefore a much wider range of available refractory substances. An electric furnace might also be constructed on these lines for delicate chemical investigations.

A tube is described in which, in addition to a concave kathode and anode arranged as in a focus tube, there is a delicately pivoted wheel, with mica vanes, which can be moved bodily either out into the centre of the tube, so that the kathode stream impinges upon the vanes, or back into an annex, when the vanes are quite outside the kathode line of fire. In the former position, as in Crookes' experiments, the wheel revolves very rapidly in a direction that indicates a stream of particles proceeding from the kathode, but when placed in the latter position, the wheel is found to rotate more slowly in the opposite direction. It appears, therefore, that in a focus tube, while the kathode stream proceeds at great velocity through the centre of the bulb, there is also a slower reverse stream of particles returning from the anode to the kathode, round the outside of the kathode stream.

When the stream from a concave kathode is caused to impinge upon an anti-kathode of carbon, the latter becomes luminescent

where struck. If the anti-kathode be so placed as to intersect either the convergent or divergent cones of rays, these, instead of producing a uniformly luminous patch upon the carbon, produce a bright ring with a dark interior. The diameter of the ring is smaller the higher the exhaustion and the nearer to the focus the point of intersection. From this it appears that the convergent and divergent cones of kathode rays are hollow in section.

Birkeland's kathode-ray spectrum, produced by deflecting a thin kathode stream by a magnet, and then allowing it to fall upon the glass walls of the tube, can be photographed by binding a strip of sensitive photographic film round the tube, and making a single discharge through the latter. Further, by inserting between the glass and the film a piece of black paper, so placed as to cover only one-half of the spectrum, a photograph can be obtained, one-half of which is due to the visible fluorescence of the glass and the other half to the invisible Röntgen rays. Such photographs show that the bands in the spectrum produced by the Röntgen rays are co-terminous with the fluorescent bands. It is suggested that the bands are due to kathode rays of different velocities, due to the oscillatory character of the discharge, those that travel fastest being the least deflected, and the most active in producing Röntgen rays.

When a focus-tube is fitted with two or more kathodes of different diameters, but all arranged to focus upon the same anti-kathode, it is found that, for any given degree of vacuum, the smaller the kathode put into use the greater is the electromotive force required to cause a discharge to pass through the tube, and the more penetrative are the Röntgen rays produced. With a tube fitted with a movable anti-kathode, half of platinum and half of aluminium, either of which can be brought opposite to the kathode at will, platinum is found to give the most rays; while similar experiments with other metals show that the metals of the highest atomic weight form the best anti-kathodes. This is in accordance with what would be expected, if the Röntgen rays are due to sudden change in velocity of the kathode-ray atoms by collision with the anti-kathode.

The resistance of a tube, and the penetrative quality of the Röntgen rays produced, can be varied by making the anode (which also forms the anti-kathode) movable, when the nearer it is placed to the kathode the higher will be the resistance and the more penetrative the rays. According to another plan, the anode is fixed and the kathode is made movable relatively to the glass walls of a conical annex to the tube, when the nearer the kathode is to the glass the higher is the resistance and the more penetrative are the rays; or instead of making the kathode movable, a conical shield of glass is arranged so as to be adjustable relatively to the kathode, with a similar result. It is suggested that the increase of resistance in each case leads to a greater velocity of the kathode stream, and thus causes the Röntgen rays to be more penetrative. Curves showing the variations in resistance, and photographs

illustrating the effect on the penetrative quality of the rays are given in the Paper.

By means of pin-hole photography, the exact position, dimensions, and shape of the active area of the anti-kathode, from which the Röntgen rays proceed, can be investigated, and such photographs show that in a focus-tube the active area is a small spot, either alone or surrounded by a hollow elliptical ring of larger or less dimensions, depending upon the distance beyond the focus at which the anti-kathode intersects the kathode stream.

The photographic effect of the most powerful Röntgen rays that can be produced is relatively very feeble. A comparative test of a very good Röntgen-ray tube screened with black paper, as against a naked standard candle, showed that the candle was sixty times more active, photographically, than the tube.

The Paper concludes with the suggestion that though Lodge was not able to detect any movement of the ether due to dragging a body through it, the very great velocity of the kathode-ray particles may have this effect, with the result that something analogous to the crack of a whip or a clap of the hands is produced as each particle hits the anti-kathode and rebounds; or the effect may be simply due to the enormous temperature attained by the kathode-ray particles on their kinetic energy being converted into heat in their collision with the anti-kathode, the energy, if all converted to heat in the particles themselves, being calculated to give a temperature rise of some 50,000 million degrees Centigrade.

AUTHOR.

Passage of Röntgen Rays along Opaque Tubes. E. VILLARI.

(Roma R. Accad. Lincei, Atti, vol. vii., 1898, pp. 225–230.)

When sent along opaque tubes they neither gain nor lose in photographic effect, and accordingly they seem not to be sensibly reflected or diffused within the tube; and they probably do not lose any of their discharging power.

A. D.

Röntgen Radiation and the Luminescence of Gases.

A. VON HEMPTINNE.

(Zeitschrift für physicalische Chemie, vol. xxvi., 1898, pp. 165–169.)

The Author investigates the property of Röntgen rays of enabling a Geissler tube, through which they are passed, to give out light under a much lower vacuum. Tberry suggested that the effect of Röntgen rays is not due to their ionising effect (at

any rate primarily), but to the rays acting upon the ether in such a way as to facilitate electric discharge-sparks between molecules, the production of milliards of which sparks is the cause of luminescence of the gas. Luminescent gas is very like a metallic conductor in many ways, even including a screening effect; but it does not absorb Röntgen rays, as metals do.

A. D.

Thermometry. C. Chree.

(Philosophical Magazine, vol. xlv., 1898, pp. 205–227, 299–325.)

A discussion of the measurement of temperature by means of glass thermometers is here presented, in which are treated the zero-difficulties and lag due to the behaviour of glass, the methods of measurement with fixed and movable zeros, and the limits of accuracy of temperature-determination. In connection with these the subject of calibration is touched upon, and the special difficulties in the determination of the fixed points, and the allowances to be made for the emergent column and for external and internal pressure are discussed at length, as is also Welsh's method of graduation. This Paper should be studied by those who rely upon glass thermometers for accuracy, and are not acquainted with Guillaume's "Thermométrie de Précision," or the work of the Bureau International, or of the Charlottenburg Reichsanstalt.

R. E. B.

Currents measured by Magnetization. F. Pockels.

(Annalen der Physik und Chemie, vol. lxv., 1898, pp. 458–475.)

The Author endeavours to determine the maximum discharge-current by the remanent magnetism induced in magnetic substances acted upon by the current. Ballistic galvanometers only give the average intensity of a current, whereas the remanent magnetism would indicate the maximum current, whenever attained. To avoid eddy-currents, the Author uses bars of basalt as the magnetic substance. The results are very favourable. A magnetic field lasting only about one-millionth of a second shows the same remanent (and probably also the same temporary) magnetization as is induced by a field kept up indefinitely at the same strength. Hence the magnetization of pieces of basalt may be used to determine the current strength of lightning discharges.

E. E. F.

Magnetic Properties of Nickel-Steels. E. Dumont.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxvi., 1898, pp. 741–744.)

The Author has continued the work of C. E. Guillaume,[1] and has examined the magnetic behaviour of nickel-steels, following the method of Prof. Ewing and Miss Klaasen (*Electrician*, May 15th, 1891). He has caused various alloys to traverse magnetic cycles, and has drawn curves showing the change of the permeability with change of the proportion of nickel, at various temperatures, and with various strengths of field. He finds that at an equal distance from the point of total loss of magnetism, all the reversible alloys have the same magnetic permeability. Moreover, at every temperature the permeability of alloys containing 27 to 44 per cent. of nickel increases with the proportion of nickel.

J. J. S.

Acetylene Compound with Cuprous Oxychloride.

R. Chavastelon.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxvii., 1898, pp. 68, 69.)

The compound $C_2H_2 \cdot Cu_2Cl_2$ is slowly decomposed into hydrochloric acid, acetylene, and a violet-coloured substance having the composition $C_2H_2 \cdot Cu_2Cl_2 \cdot Cu_2O$. The decomposition is incomplete in presence of hydrochloric acid.

T. E.

Sulphating of Negatives in Lead Accumulators. L. Jumau.

(L'Éclairage Électrique, vol. xvi., 1898, pp. 133–136.)

The evolution of hydrogen and formation of lead sulphate at the negative plates while the element is at rest is due to two principal causes—(1) the chemical action of the sulphuric acid upon spongy lead; (2) the electrochemical action of the couple formed by the spongy lead of the active material and the lead (often containing antimony) of the support. The accidental presence of particles of lead peroxide from the positives, or of copper from the connections, also favours sulphating, whilst the action is in all cases much increased by the use of acid of high density. The results of experiments are given showing the influence of acid-concentration, and of time on the sulphating of charged plates at rest. In many cases the extent of the action is greater than can be attributed to the above-mentioned causes, and is found to be due to the presence in the active negative material

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[1] Comptes Rendus de l'Académie des Sciences, Paris, vol. cxxiv., 1897, p. 1515, and Physical Society's Abstracts, 1897, No. 517.

of iron, and, more especially, of antimony. The latter is derived from the alloy of which the grids are composed, and is found almost entirely in the superficial layers of the active material. The experiments quoted show the great influence of small percentages (under 1 per cent.) of antimony upon the sulphating, especially in combination with acid of high density. It is recommended that soft lead, free from antimony, be employed for the positive plates, or, if this is impossible, that electrolytes of low density be used. It is often advisable to remove the superficial layers of spoilt negatives, notwithstanding the decreased capacity caused by this operation.

J. W.

Comparative Cost of Ozone. J. B. C. Kershaw.

(Electrical Review, vol. xliii., 1898, pp. 151–153.)

The writer gives, first, brief descriptions of each of the five following forms of ozonizer:—Andréoli, Otto, Yarnold, Siemens and Halske, Tindal and Van der Steen. The proposed applications of ozone are then enumerated, and these are submitted to a detailed examination as regards comparative costs of ozone and the oxidizing agents at present in use for the purposes named. The two following Tables give, in condensed form, the results of the writer's calculations:—

Table I.

Form of Ozonizer.	Yield of Ozone in grams per E.HP.-Hour.	Cost of Electrical Energy. Per kilogram of Ozone.	Cost of Electrical Energy. Per kilogram of Active Oxygen.
		d.	d.
Yarnold	175	8·56	25·68
Otto	150	9·99	29·99
Andréoli	90	15·90	47·70
Siemens and Halske .	20	75·00	225·00
Theoretical figures . .	1,000	1·50	4·50

Table II.—Comparative Costs of 1 kilogram of Active Oxygen.

Source.		Cost.
		d.
Bleaching powder		18·8
Sodium bichromate		48·0
Ozone	Yarnold's ozonizer	61·5
Ozone	Otto's ozonizer	66·0
Ozone	Andréoli's ozonizer	83·7
Sodium manganate	Acid solution	86·0
Sodium manganate	Alkaline solution	153·0
Ozone	Siemens and Halske's ozonizer . .	261·0

The writer holds that these figures prove—

(1) That bleaching-powder is still the cheapest oxidizing agent, and that for those purposes for which it is applicable and gives good results it will not be displaced by ozone.

(2) That ozone will be a keen rival to sodium bichromate and sodium manganate in the manufacture of oils, fats, and organic products, and that in time it will probably displace these chemicals.

(3) That the extended application of ozone for producing results at present obtained by atmospheric influences—as, for instance, the purification of water, maturing of wines and spirits, etc.—is uncertain, and that further trials may result in failure due to economic and chemical causes.

AUTHOR.

Practical Working of Accumulators. L. GEBHARD.

(Zeitschrift Elektrotechnischen, Wien, vol. xvi., 1898, pp. 261–265 and 277–280.)

After a brief historical introduction, the Author deals with the improvements introduced during the past few years into the manufacture of the peroxide plates, the construction of the cell as a whole, and the management of cells. The gradual evolution of the modern type of Planté plate is fully considered, and its advantages over the pasted form of plate are pointed out. The application of modern accumulators capable of giving a high rate of discharge to electric traction is next considered; and the Hanover system is instanced as a successful example of what may be done in this direction.

A. H.

Insulation and Conduction (Part II.). R. A. FESSENDEN.

(American Institute of Electrical Engineers, vol. xv., 1898, pp. 204–227.)

This is mostly a statement of facts and experience with regard to insulators. Rubber and ebonite are objectionable, because their surface becomes acid. It may be protected with paraffin. Glass is objectionable, because the alkali in it has a great affinity for moisture; also the angle of contact between water and glass is zero, and a drop of water spreads indefinitely. Quartz fibre is invaluable, becomes the water slides off. There is no reason why a suitable glass should not be designed. Porcelain with a non-alkaline glaze is excellent. For insulating coils paraffin is objectionable; its large coefficient of expansion strains the delicate wires. Rubber in contact with copper rots.

Manganin and constantan are unsatisfactory resistance-materials; pure lead run into glass tubes and kept in water has been adopted

for standard resistances. Paraffin is best for condensers, and will stand 500,000 volts per inch.

Homogeneity in a dielectric is essential to volt-resistance. Thus, introducing a plate of glass into an air dielectric which is on the point of rupture under a high voltage alternating will precipitate that rupture.

The specific inductive capacity of oils may be reduced by expelling all the water. Silk should never be used in induction-coils where pure cotton can be had. The Author considers that J. J. Thomson's discovery of the greatly increased dielectric strength of air with increased pressure should be used for cable-work. Thus air at 90 lbs. per square inch is equal to good rubber. Ice as a dielectric for cables is also suggested. Armatures may be insulated with asbestos string soaked in silicate of soda.

Insulation may be applied to cloth as a backing, but water creeps in at the edges and where the little tubes of cellulose protrude. Similarly with impregnated cloth (using, say, varnish dissolved in alcohol) the material in the tubes becomes filtered free of the gum, and will not be protected from water, which will be sucked up by the tubes. For impregnation no substance may be used dissolved in another substance. Few substances which melt are elastic: there is a valuable exception, viz., imitate, commonly called gilsonite. It mixes with paraffin. Linseed oil has the advantage of expanding on drying, thereby filling the pores of any cellulose it may be used upon. No lead drier must be used with it, and for armatures pure raw oil is best. Time is gained by the employment of borate of manganese as a drier. The pure linseed oil is boiled at about 200° for several hours with ½ per cent. of borate of manganese till it begins to thicken. It always remains sticky.

A useful soldering fluid is obtained by dissolving resin in strong ammonia and using the soap as flux. An alarm against overheating can be made by imbedding a spring and contact in carnauba wax. The wax remains solid up to the danger-point, and suddenly melts.

M. O'G.

Liquid Resistances. G. Dary.

(Électricien, vol. xv., 1898, pp. 273–275.)

This Paper discusses the advantages and disadvantages of liquid resistances with acid and alkaline electrolytes, and describes some experiments made in Baltimore, U.S.A., with a resistance consisting of two cylinders of galvanized iron mounted concentrically on a vertically-adjustable frame and cut off obliquely towards their lower ends, so that the surface wetted increases gradually as the cylinders are immersed, the current passing from one to the other through the liquid.

C. K. F.

Electric Revolution-Indicator. G. Dary.

(L'Électricien, vol. xv., 1898, pp. 292–293.)

This indicator, devised by Mr. Cadiou, serves to indicate each revolution made by the propeller-shaft of a vessel and also the direction of rotation. For this purpose, it comprises a rod pivotally supported at or near its centre, and normally held with one end midway between two contacts by means of springs, the other end of the rod being provided with a roller adapted to be acted upon by a cam on the propeller-shaft. By these means, for each revolution of the shaft the rod can be caused to touch one or other of the contacts, and, by suitable connections with the lighting circuits of the vessel, to intermittently illuminate one or other of two incandescent lamps, according to the direction of rotation. By counting the number of times the particular lamp lights up in unit time, the speed of the shaft can be determined. When the intermittent illumination is transferred from one lamp to the other, it can be seen that the engines have been reversed. It has been found to work satisfactorily, during a six months' trial, up to 110 revolutions per minute, on board the "Condor."

C. K. F.

Electric Capstans. E. Sartiaux.

(L'Éclairage Électrique, vol. xv., 1898, pp. 459–469.)

This Paper gives a description, with clear drawings, of electric capstans in use on La Compagnie du Chemin de Fer du Nord, and comprise (1) a capstan proper for haulage; (2) a direct-acting capstan for the rotation of turntables and swinging-bridges; (3) a geared capstan for actuating a number of turntables or a hauling apparatus, as desired. In the first of these arrangements the hauling drum or head is mounted directly on the shaft of a series-wound 8-pole motor, mounted on a platform supported on trunnions in a cast-iron cauldron-shaped base, so that it can be reversed for inspection or cleaning. The second arrangement is similar to the first, except that the motor-shaft is provided with a sprocket-wheel driving the turntable or swinging-bridge through a driving-chain; the sprocket-wheel on the motor-shaft is connected thereto through a friction-clutch, the sections of which are held in engagement with each other by means of a spiral spring, this arrangement allowing the motor to stop gradually, even when the motion of the turntable or bridge is suddenly arrested. In the third arrangement the motor-shaft is provided at its upper end with a hauling-drum or head, and also with a gear-wheel which gears with three pinions capable of being connected to sprocket-wheels by means of friction-clutches operated by electro-magnets, the

said sprocket-wheels driving turntables or swing-bridges through chains. The motors are driven from accumulators, a kilowatt-hour costing about 0·2 franc (1·9*d.*), the cost of each operation of a capstan varying between 0·004 franc and 0·005 franc. The first type costs 5,500 francs (£220), the second 6,500 francs (£260), and the third 9,000 francs (£360); this comprises the switches and conductors. The supply is at 100 volts to 110 volts, the normal current varies from 30 amperes to 35 amperes for a pull on the cord of 400 kilos, and 70 amperes to 75 amperes for 1,000 kilos; the motor-shaft making 12 revolutions to 16 revolutions per minute. The descriptions are full, and are supplemented by a number of clear drawings and curves.

C. K. F.

Electric Elevators. W. C. C. Hawtayne.

(Electrical Engineering, vol. xxi., 1898, pp. 693–697.)

This Paper, after briefly sketching the development of the electric elevator, gives full descriptions of several types of the Otis elevator, with starting, stopping, and safety devices, and also of the electric elevators made by Messrs. Waygood and Co., Messrs. Easton, Anderson and Goolden, and the Sprague Electric Company.

C. K. F.

Single-Phase Alternating Current Motors. E. C. Hoadley.

(Electrical Review, vol. xliii., 1898, pp. 66–68.)

This is an article on the performance of the single-phase motors working on the Worcester supply mains. The maximum load on the station is 330 kilowatts, and of this 120 kilowatts are supplied by means of water-power, the remainder being accomplished by steam. The current is generated at 2,000 volts at a frequency of 100 cycles per second, and is distributed at 100 volts. The motors driven from the station aggregate 100 HP.: of these some are synchronous and some induction motors made by the Oerlikon Company and the Langdon-Davies Motor Company. Little difficulty is experienced in the regulation of the plant unless a motor is suddenly switched on during a period of light station-load. During periods of light load it is found profitable to supply current for motive power at 1½*d.* per unit. When motors are run during periods of heavy load the charges are as follows—

Not exceeding 1,000 units per quarter	3*d.* per unit.
Over 1,000, not exceeding 2,000 units per quarter .	2½*d.* „
Over 2,000, not exceeding 5,000 units per quarter .	2*d.* „
Over 5,000 units per quarter	1½*d.* „
Motors which do not use as many units as a 1-hour's daily use of their minimum demand	6*d.* „

The power-factor of the Worcester plant varies from 0·5, when the load is light and composed chiefly of motors, to 0·98, when the load is chiefly glow lamps. The efficiencies of the motors vary from 75 per cent. to 84 per cent. according to their sizes. If the load of an alternating-current station consists partly of motors, the alternators should have no iron in their armatures, otherwise there will be considerable variation in the lights on switching on motors.

W. G. R.

Patton Motor Tram-Car.

(Street Railway Journal, vol. xiv., 1898, p. 226.)

Figures are given relating to the test of a Patton car, which was run 274·1 miles on the Great Western Railway (U.S.A.). The time taken in running this distance, omitting stops, was 16 hours 45¼ minutes. Taking gasoline at 5 cents (2½*d.*) per gallon, the cost of fuel amounted to $1\frac{1}{17}$ cent (0·53*d.*) per car-mile, or $0·00064 (0·032*d.*) per ton-mile.

W. R. C.

Selector System of Circuits. J. Voisenat.

(L'Éclairage Électrique, vol. xv., 1898, pp. 393–400.)

This is a system for operating any one of a series of local circuits on a single line, independently of the others. Each local circuit is controlled by a rotary electromagnetic switch, designed to rotate by steps as dots and dashes are received from line. To each switch corresponds a certain sequence of dots and dashes; if this particular sequence is "received," the switch actuates the local circuit; but for any other sequence the switch has no effect on the local circuit. The sending arrangement on the line-circuit is "automatic"; the sequences of dots and dashes are represented by teeth in the edges of rotating disks, any one of which can be brought into play, according to the particular local circuit to be operated. As a matter of detail, there are two disks on the "sending" apparatus, corresponding to each local circuit; so that positive and negative signals take the place of dots and dashes.

R. A.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1898–99.—Part I.

N.B.—Titles in italics refer to Original Papers, and those selected for printing only are further distinguished by the suffix "(S.)." Abstracted Papers are not so indicated.

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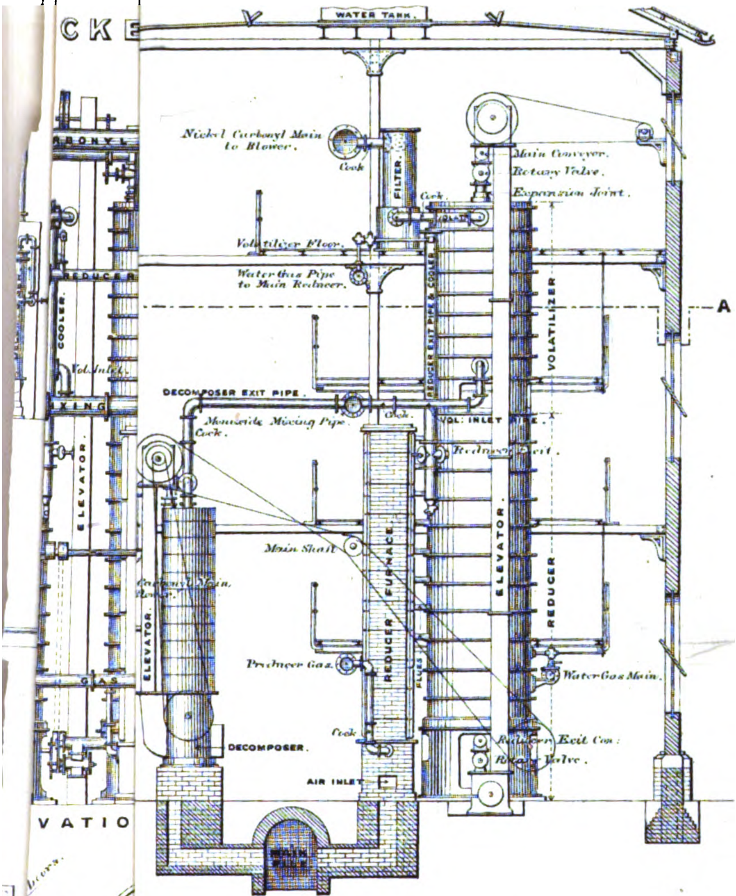
PLATE 1.



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SCALES

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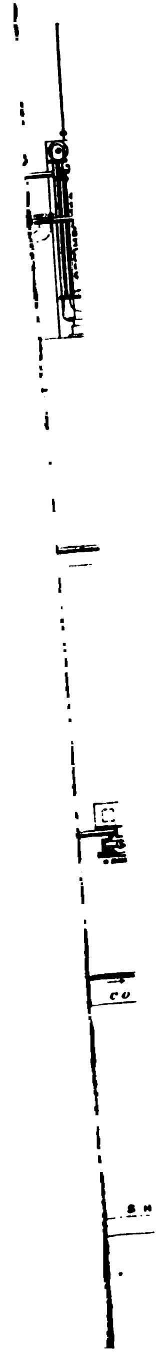

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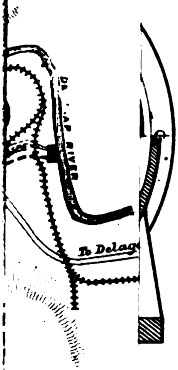
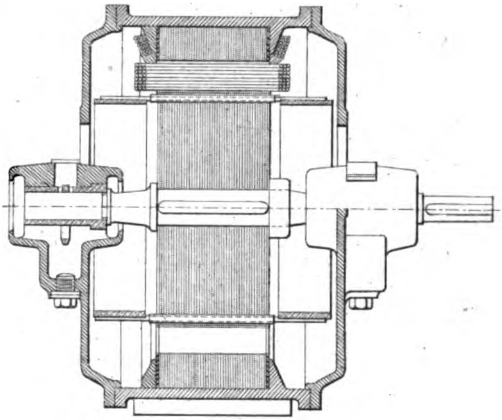
PLATE 2.

Figs. 8.





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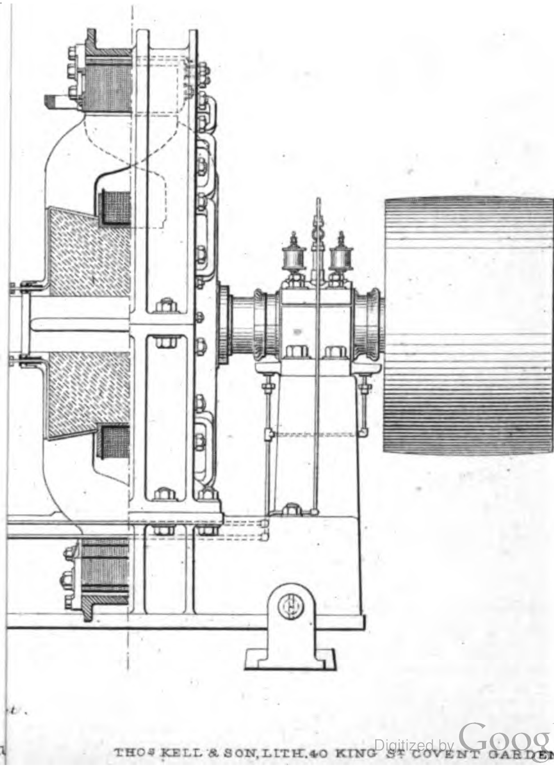

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THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

PLATE 6.

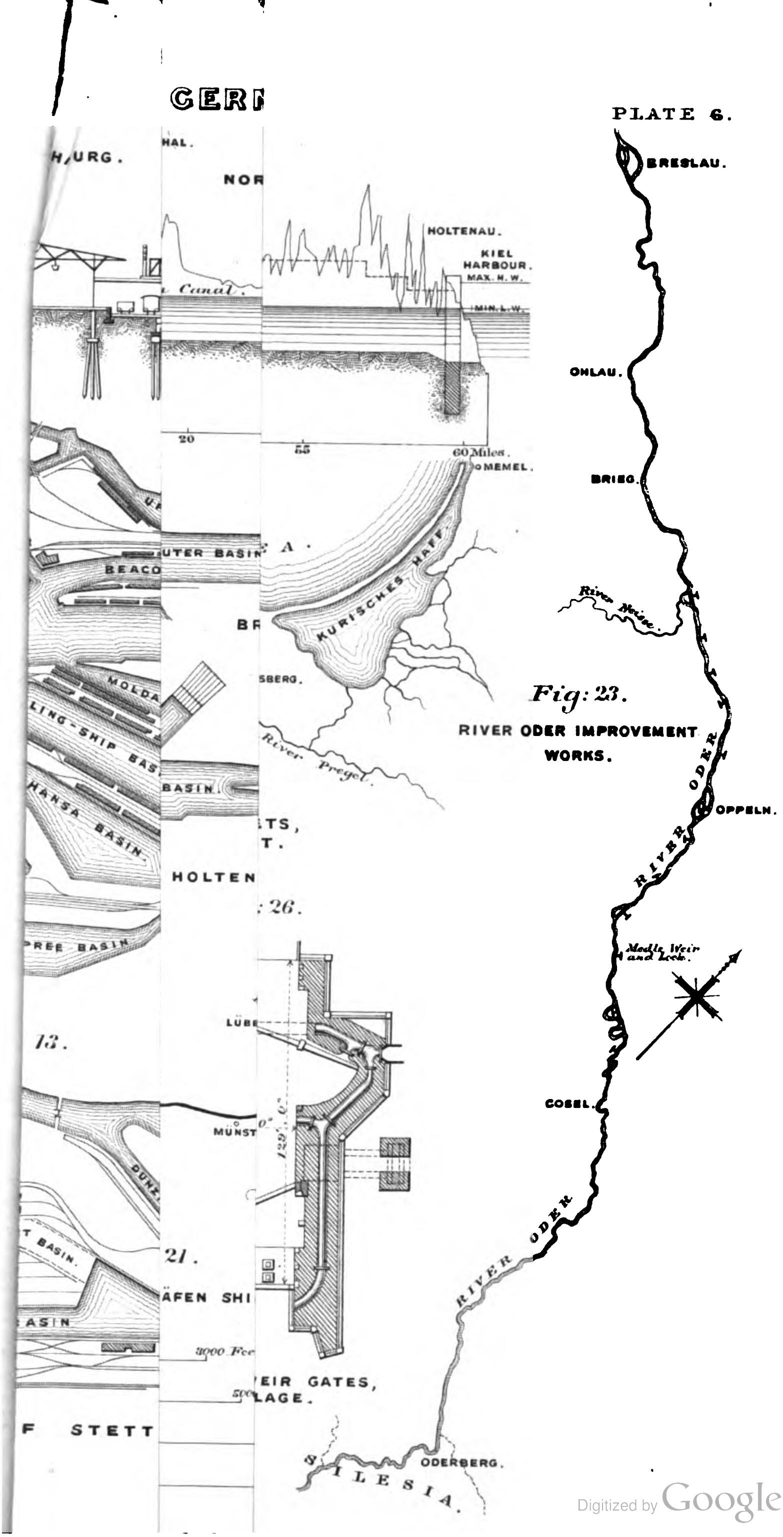

Fig: 23.

RIVER ODER IMPROVEMENT WORKS.